New-World Science Series

SCIENCE FOR BEGINNERS

FALL

NEW-WORLD SCIENCE SERIES
Edited by John W. Ritchie

SCIENCE FOR BEGINNERS

A First Book in General Science
for Intermediate Schools and
Junior High Schools
by

DELOS FALL, D.Sc.
Professor of Chemistry, Albion College
Formerly Michigan State Superintendent
of Public Instruction

ILLUSTRATED BY
Will H. Schanck and Elliott Dold

Yonkers-on-Hudson, New York
WORLD BOOK COMPANY
1917

WORLD BOOK COMPANY

THE HOUSE OF APPLIED KNOWLEDGE

Established, 1905, by Caspar W. Hodgson

YONKERS-ON-HUDSON, NEW YORK
2126 PRAIRIE AVENUE, CHICAGO

The purpose of this house is to publish books that apply the world's knowledge to the world's needs. Texts in science offer unusual opportunities for the realization of such a purpose, and it is intended that each volume of the New-World Science Series shall be a concrete expression of this ideal of educational service. Editor and publisher take pleasure in offering for use in intermediate schools and junior high schools Fall's *Science for Beginners*, the first book of the series, and announce that other volumes for use in junior high schools, high schools, and colleges will follow

NWSS : FSB–I

PREFACE

Only a generation ago, it was the prevailing idea that all instruction in schools and all learning by pupils should be confined to the schoolroom and to books. Nature study was unknown, except that once in a while curious relics from foreign countries were brought in to emphasize some phase of the pupil's study. A little later more material was taken into the classes and used to verify to some extent the statements of the books. But these were only fragments of the part of nature which they represented, and for that reason aroused very little interest in either teacher or pupil. Out of this somewhat fragmentary study has grown the laboratory method which is used in the better schools at the present time. But even yet there is not enough use of the real thing and the whole thing. The material for study is gathered by the teacher or is furnished by the school authorities, and the pupils are required to handle only those portions which will illustrate the point under discussion.

Gradually, however, teachers are coming to see that to get the best results the pupil must, whenever possible, gather his own material. When this point is conceded, it is readily agreed that the pupil may oftentimes study his materials to greater advantage in their natural environment. The inevitable conclusion to be drawn from all such reasoning is that in many cases the study of nature requires that the pupil should go out of doors and, under proper guidance, observe, examine, describe, reason upon, and finally draw his own conclusions concerning the matter in hand.

It is suggested that the less help the pupil has the better he will do his work, provided he is given necessary instructions and encouraged to go on to the end of his study. After he has exhausted his own resources in a given problem, it is the teacher's part to contribute by supplementing and enriching the knowledge which has been obtained by the pupil.

But until the work of the pupil is done, the rôle of the teacher should be one of masterful inactivity.

The teacher is asked to keep in mind that the chief purpose of this book is not to give the pupils a large amount of information, but rather to introduce them to a method through the use of which they will acquire the habit of gaining information for themselves. The scientific method, by which is meant that methodical procedure which is more and more coming to be used in all lines of human activity, is most easily applied in the field of the natural sciences, and the pupil can best learn the method of the scientist by using the material with which the scientist works.

The author makes no apology for the constant use of the direct address. The book is a direct message to the user of it, and it is to be hoped that the teacher will encourage the idea that here is the boy's and the girl's own book.

For helpful suggestions the author is under obligations to Miss Marie K. Dunn, Teacher of Science, Junior High School, Solvay, New York; Donald P. Boyer, Principal Bellevue Junior High School, Richmond, Virginia; Stanley S. Foote, Lincoln Intermediate School, Santa Monica, California; Harry A. Richardson, Teacher of General Science, Junior High School, Kalamazoo, Michigan; Professor William J. Bray, First District Normal School, Kirksville, Missouri; and Dr. Albert Leonard, Superintendent of Schools, New Rochelle, New York; each of whom read the manuscript in its original form. He is also indebted to Professors Clarence W. Greene and Frank W. Douglas, Albion College, and to Professor William H. Keeble, College of William and Mary, for valuable aid in the preparation of the chapters dealing with physical subjects, and to Dr. William C. Bagley, of Teachers College, Columbia University, for reading the discussion of the scientific method found in the opening chapters.

CONTENTS

TO THE BOYS AND GIRLS WHO USE THIS BOOK

The writer of this book remembers very clearly that in his boyhood days he had an intense desire to investigate those things that were immediately about him. He had a dim notion that the problems of everyday life would prove most interesting if they could be solved in some way by himself. To him it seemed far more captivating to obtain knowledge through his own experiments than by merely reading from a book. This thought has remained with him all through the years, and it is because of it that this book has been written; the purpose has been to provide a book that will permit you to get the information for yourself.

The writer confesses one great anxiety, however. Will you, the boys and girls who use this book, have the courage to carry on the work in accordance with the spirit of the book? Will you do the work for yourselves, make the observations, keep a notebook, and so learn to know by doing?

If you desire to secure the best results from the use of this book, or any book for that matter, you must have a well-laid-out plan and must not do your work in the haphazard way that is characteristic of many boys and girls of your age. You are asked to study carefully the suggestions that follow, and, if you think them worth adopting, to observe them to the best of your ability.

1. Make out a definite daily program for every hour of the day, and especially the exact time that you will devote to each of your studies.

2. Provide yourself with all the tools you will need

for the prosecution of your work, — textbook, notebook, pencil, eraser, practice paper for first notes, ruler, and, if possible, a good dictionary.

3. Learn to make the best use of your textbook. Give attention to chapter and paragraph headings, to words that are marked with a star, and to statements that are underscored. Examine the pictures carefully. Every one of them teaches some important truth. Use the index, give attention to footnotes, and study out the meaning of the design on the cover. How to use a book is an art that you should learn.

4. Study by yourself. Solve your own problems and do your own thinking; for in this way only will you grow as a scholar.

5. Studying is simply intensified reading. Therefore learn to read in such a way as to get the real thought. "One hour's bright, wide-awake, concentrated, interested study is worth a day's plodding."

6. Find and state the problems in the subject you are studying. You are well on the way to knowledge when you know exactly what you want to know.

7. Never ask another person to answer a question if by thinking you can answer it for yourself; but never go without a necessary bit of knowledge that you can gain by asking a question.

8. Learn to use the method of experiment in order to find answers to many questions that will arise in your mind.

9. Remember that the book is only a guide to show you where and how to look for truth; and remember also

that the truth is hidden away, not in the book, but in the object of your study. What that truth is, you must see for yourself. It would be unfortunate for you if the book or your teacher were to give you information which by observation or experiment you can get for yourself.

10. Learn to use all your senses; train your mind to notice what your eyes see; train your ears to hear and recognize sounds; train your hands to feel, for many times they are far better than your eyes.

11. Give attention to natural objects and to what is happening in nature about you. You may not understand all you observe just now, but sometime in the future what you are now seeing will become a valuable part of some learning process.

12. Think about what you have learned. Talk it over with your classmates and especially with your parents or older brothers and sisters. In this way you will bring your ideas together and learn the answers to questions that naturally arise. Thus you will learn to apply your knowledge to the daily experiences of life and to use it in a practical way.

SCIENCE FOR BEGINNERS

CHAPTER ONE

SCIENCE AND THE SCIENTIFIC METHOD

FIGS. 1 and 2. Sometimes you can find the answer to your questions by observation; sometimes you will need to employ the method of experiment.

THIS is a book in elementary science, and the pupil who uses it is asked to be a scientist. This means that he must work as a scientist works; think as a scientist thinks; and in this way find out for himself some of the things that other scientists have learned. In order that he may begin his studies in the right way, he should know what science is and how a scientist goes about his work.

What science is. Science is defined as knowledge of any given subject properly arranged and classified. A person may know a great many facts about a given thing, but if his knowledge is not arranged according to some system or plan it cannot be called scientific

knowledge. For example, an Indian may know the names of many of the plants that grow in the woods, when and where to look for them, how to compound medicines from them, and when their fruits will be ripe; but he cannot be called a scientific botanist, partly because his knowledge is not extensive enough, but more particularly because it is not organized and because his ideas have not been verified by exact observation and experiment.[1]

The scientific habit. In using this book you will often be asked to make observations and experiments, and to arrange or tabulate in an orderly manner the facts that you collect, so that you may grow into what may be called the scientific habit. The most important thing that can be learned from a study of science is the method of thinking and working which the scientist uses, and you will be asked to do things in a scientific way in order that you may learn this method. Then you will be able to apply the method of science in all your work as long as you live.

The scientific method. By using the scientific method you can answer many of your own questions without the aid of a teacher. Sometimes you can find your answers by careful observation; sometimes you will find them only by experiment. By one or the other of these two methods men of science have made all their inventions and discoveries, and through their use scientists

[1] Science is knowledge gained and verified by exact observation and correct thinking, especially as methodically formulated and arranged in a rational system. — *Standard Dictionary.*

FIG. 3.

are every day asking questions of Nature and receiving their replies from her. The value of the scientific method lies in the fact that it enables us to gain new knowledge; by its use we can get information for ourselves without the aid of teachers or the use of books.

Illustrations of the method. An understanding of the scientific method is so important that we shall give several illustrations of how it is used. Suppose, for example, that you see what looks like a load of wheat in bags, passing your house, and you wonder how heavy the load is. You observe that the bags are in three rows with 8 bags in a row, and that there is an additional bag on top of the load. How many bags are there? You already know that bags of this kind hold 2 bushels. How many bushels are in the load? A bushel of wheat weighs 60 pounds. How many pounds

in the load? A ton is 2000 pounds. How many tons in the load?

When you have made your calculations, you have answered the question for yourself. By the use of your eyes and your mind, you have learned the weight of the load of wheat.

Steps in the process. In working out a problem like the above, your mind goes through four, and sometimes five,

FIG. 4. The boys wonder what the tortoise weighs.

FIG. 5. They make their observations.

separate steps, all so woven into each other that they form one continuous story. These steps are as follows:

(1) Your attention is attracted to some unusual object or incident and you wonder what it is or what it is all about; you are curious to know; your interest is aroused. This is the first step in starting a train of thought in your mind, and the next step in the process ought to be a careful examination of that which has aroused your curiosity.

(2) You see certain things with your eyes, or you learn certain facts through your hearing or some other one of

your senses. This step, which we call observation, is the most important step of all, because it forms the basis of what follows. What you are observing may be something that occurs about you in nature; but often it will be necessary to make an experiment and watch its progress, in order to get the facts you desire.

(3) You quickly recall what you already know about the thing you are now seeing or hearing. You have seen

FIG. 6. They recall the weights of different objects.

FIG. 7. They conclude that the tortoise probably weighs about 2 pounds.

something like it before and you already know some facts about it. These facts are brought together and added to what you are now learning by observation. By this process your knowledge of the object is enlarged and enriched; and a more thorough observation might furnish you with other facts that would add still more to your knowledge of the object.

(4) The fourth step is to come to some conclusion as a result of your study; to form some hypothesis, or

theory, that will explain what you have observed. The conclusion, or hypothesis, must be so definite that it can be expressed clearly. Notice that the more accurate your observations have been and the more you are able to add to them from previous experiences, the more definite and clear will be the conclusion you are able to reach.

(5) A fifth step must frequently be taken by the scientist. It may be called the step of verification. We are not always sure that the conclusion we reach is the exact truth, and we should stand ready to change our views when new facts or principles come to our knowledge. Many times we may verify, or prove, the truth of our conclusions by further questions or experiments, and whenever it is possible this should be done.

FIG. 8. They verify their conclusion.

To understand this method better, let us now write out all that passed through your mind as you studied the incident of the load of wheat. In order to help in keeping each step separate from the others, the second one is printed in ordinary type; the third step — that part of the process in which you recall what you have previously learned — is inclosed in quotation marks; and the fourth step, or conclusion, is in heavy-faced type. The complete scientific story would run something like this:

I see 3 rows of bags with 8 bags in each row and there is one extra bag on top of the others; **3 times 8 bags is 24 bags and one more makes 25 bags.** "It is probably wheat." "Each bag contains 2 bushels." **There are 2 times 25, or 50, bushels in the load.** "A bushel of wheat weighs 60 pounds," **so the load weighs 50 times 60 pounds, or 3000 pounds.** "2000 pounds make one ton," hence **there are $1\frac{1}{2}$ tons on the wagon.**

If you had become interested in this incident and your mind were active, perhaps you would not stop at this point. It is possible that you would go to the market to find whether this was really a load of wheat or not, and what was its exact weight. In this way you would verify your conclusion and thus carry out the fifth step of the process. You would, perhaps, also ask the farmer how many acres of wheat he had raised and how many bushels per acre he had secured; you would learn what it is worth a bushel and compute the value of the wheat per acre. Your mind would perhaps also turn to the number of acres of wheat raised in the United States each year, the average yield per acre, the total number of bushels in the crop, where the wheat will be marketed, and the uses that are made of it. If you are not interested in such mental exercises, perhaps you will ask yourself why you do not like to think.

Another illustration. Other illustrations may help to give a better understanding of the scientific method. I see a man on the street clad in a strange costume and become interested in him. His outer garment, "I can hardly call it a coat," is made of that peculiar kind of

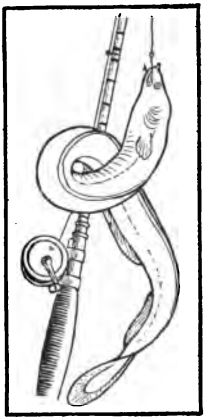


FIG. 9.

cloth known as "plaid"; I notice that his clothing comes only to his knees, and that his legs are bare from the knee down to the tops of his plaid stockings; then, "I remember that such cloth and costume are worn in the northern part of Great Britain." I conclude that **he must be a Scotchman.** I observe that he carries a strange instrument and when he puts it to his mouth it gives out an unusual sound. "It is probably a musical instrument"; **it is a pair of bagpipes.**

When I return home, I look up bagpipes in the dictionary and find a picture of a Scotch Highlander with an instrument like the one I saw on the street. I have tested my conclusion and found it correct.

A third illustration. I go fishing; presently I "get a bite"; I feel something tugging away at my line. **It must be a fish.** I draw it out. "What a strange fish!" It is long and slim and slippery; it has no scales. **It cannot be a common fish.** I let it touch the ground and it quickly ties my line into knots. "I have heard a fisherman say that eels do this." "I remember a picture of an eel that I have seen." **It is an eel.**

Still other illustrations. I am traveling on the cars; we pass through a city in which I see some very high buildings. "Tall buildings are found only in large

cities." **This is a large city.** "I remember that Grand Rapids is one of the principal cities on the railroad running from my home to Chicago." **This must be Grand Rapids.** I now consult my time table to see when we are due at the Grand Rapids station and find that we should be there in two minutes. The brakeman tells me that the train is on time; so I am sure that this city is Grand Rapids.

Two girls are expecting to go on a picnic. Early in the morning they scan the sky. Dark, threatening clouds are gathering in the east. "It is going to rain"; **we cannot go**! They continue to study the sky, and presently the clouds break away and the blue sky appears. "It is clearing up"; **it will not rain after all and we can go.**

Two boys are roaming the fields with their eyes wide open to see what they can find that is valuable or interesting. They find some bright, glistening, yellow particles as a part of a rock. "It looks like gold. I wonder if it is gold." How shall we find out whether it is gold? "I've heard my father say that a mineral called fool's gold is almost as bright and as yellow as real gold."

They carry a piece of the rock to their teacher, and he takes them to the chemical laboratory. He tells them that what is called "fool's gold" is not gold at all, but a compound of iron and sulfur. We can tell what it is by an experiment. If it is pure gold it will not dissolve in hydrochloric acid; if it is fool's gold it will dissolve in the acid and will give off a disagreeable odor which will remind one of decaying eggs. Pure gold is

soft and can be whittled with a knife. Fool's gold is hard and generally separates from the rock in small, flat scales. The tests are made. The yellow mineral dissolves in the acid. **It is fool's gold.** By the scientific method the answer to the question has been found.

Two additional advantages of the scientific method. This is a much better method of getting knowledge than merely reading in a book, because we can understand and use better the knowledge we have worked out for ourselves, and also because by this method we learn to do our own seeing and thinking and thus become able to get information that is not to be found in books. That "thing knowledge is better than book knowledge" you will readily understand, and when you remember that the answers to the problems that meet us all through life are not written out in books, you will appreciate the importance of a method that will enable you to get for yourself the information you will need in solving these problems.

A clever scientist. Near the end of the season a boy announced the height of a tall tree to be 33 feet.

"Why, how do you know?" he was asked.

"Measured it."

"How?"

"Foot rule and yardstick."

"You didn't climb that tall tree?" his mother asked anxiously.

"No'm; I just found the length of the shadow and measured that."

"But the length of the shadow changes."

FIG. 10. Measuring the height of a tree.

"Yes'm; but twice a day the shadows are just as long as the things themselves. I've been trying it all summer. I drove a stick into the ground, and when its shadow was just as long as the stick, I knew that the shadow of the tree would be just as long as the tree, and that's 33 feet."

CHAPTER TWO

WHAT THE YOUNG SCIENTIST MUST LEARN TO DO

THE scientist collects his facts or principles, arranges them so that they will give an orderly view of the subject as a whole, and then draws his conclusions from them. Described in this way the method of the scientist seems simple; but in reality it requires skill and care to collect facts and arrange them so that their meaning will be clear. It is very important, therefore, that the pupil who is just beginning his studies in science should understand what he must do to carry out the scientific method successfully. This subject we shall discuss in the present chapter, but it should be remembered that it is only by using the method that a real mastery of it will come to you. "Thing knowledge is better than book knowledge," whether it be in baseball, in arithmetic, or in the method that the scientist uses in his work.

The scientist must learn to observe. To observe is to take notice; to see; to give attention to what one sees and hears; to perceive; to discover; to learn. The scientist must observe because it is through observation that he collects his facts. Have you the ability to observe accurately? Can you see clearly and can you hear distinctly? Are all your senses wide awake and on the alert? In a word, are your powers of observation strong and active, and have you formed the habit of observation? A few tests will help you to answer some of these questions.

Exercise 1. Let the teacher place a few articles on the table and cover them with a cloth or paper. Let the cover be removed for a minute and then let each pupil make a list

of the articles. What would be your marking on the scale of a hundred in this test?

Exercise 2. Let the teacher remove some of the articles from the table and disarrange the others. Then let the pupils call for the objects that have been removed.

Exercise 3. If you live in the country, make from memory a list of the tools and machines left without proper shelter that you noticed on your way to school in the morning. Look again when you go home in the evening. Let different pupils do this and compare their lists.

Exercise 4. Make an inventory, from memory, of the objects in some room at home, — the sitting room, for example. Take the inventory home and find out how many prominent objects you have omitted.

Exercise 5. Make from memory a picture of the face of the clock at home. What figure is at the top? Which is at the bottom? What kind of figures are used? Do the same for your watch if you have one. In each case verify your results.

The scientist must learn to measure. The first and most important step in all scientific work is to get the facts and get them right. By the use of rules, scales, and other measuring instruments we can help our eyes and ears and other senses to make our observations much more exact. All our modern sciences, but especially physics, astronomy, chemistry, and mathematics, rest upon the ability of the scientist to make exact measurements. For linear measurements we use the inch, the foot, the centimeter, or the meter; for areas, the square inch, square foot, square centimeter, or square meter; for cubic measurements, the cubic inch, cubic

foot, cubic centimeter, or cubic meter. For measuring volume we use the liquid pint, quart, or gallon; the dry pint, quart, or peck; the liter and its subdivisions and multiples.

In the laboratories of our universities, scientists can measure the size of a disease germ that is only one fifty-thousandth of an inch in diameter; they can weigh the ink that you use in writing your name. Fine measurements like these are, of course, far beyond your present power; but if you wish to make true progress in even elementary science, you must become thoroughly acquainted with the units of measurement with which scientists work. The best way to become acquainted with these units is to use them, and a pocket rule is an excellent companion for the knife that is to be found in the pocket of almost every boy.

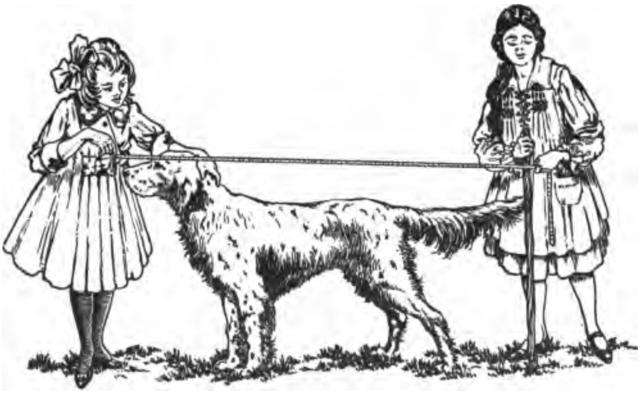


FIG. 11. The best way to become familiar with the units of measurement is to use them.

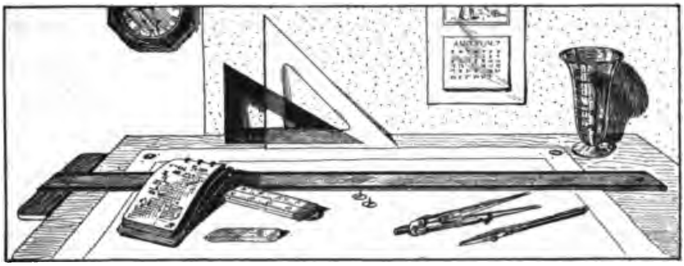


FIG. 12. Some tools that a young scientist should learn to use.

The young scientist must learn to record. Our recollections of what we have seen and heard are too scattered and unreliable to allow us to depend, in our scientific work, on what we remember. A third thing, therefore, that the young scientist should learn to do is to keep a record. He should be able to use drawing instruments well enough to make a diagram or plan that will aptly illustrate his thoughts. He should become skillful in tabulating his knowledge, a process which will be fully explained and illustrated in this book.

It is a good plan always to have at hand a notebook into which anything of importance may be put. Keeping this book will afford many opportunities to practice and develop the power of recording, and it will cause as much mental growth as anything the pupil can do.

Classification necessary in science. Science is classified knowledge, and learning to classify is an important part of a scientific training. Let us clearly understand what is meant by the term "classification," and also how a scientist must constantly use it in order to reduce his knowledge to a scientific form.

Two steps in the process of classification. Classification consists of two separate steps: (1) the choice of a proper basis for classification, and (2) the reference of the things to be classified to that basis.

For example, suppose we should take our stand at a favorable place upon some crowded city street, and make a classification of the people as they pass by, and suppose that we were to take sex as the basis of our classification. This would require us to refer each person either to the class male, or to the class female. In most cases this could easily be done, but in the case of some foreigners, with their queer costumes, there might be difficulty in making an accurate classification.

Or suppose our task were to classify them as men, women, boys, or girls. The difficulties would be somewhat greater than before, as it could not always be easily determined, in a given case, whether a person was really a boy or had passed the line between boyhood and manhood. If we were required to classify them as to height, the problem would require that every person be halted long enough to have his measure taken. If the basis of classification were nationality, and we desired to do the work very accurately, then every person would be required to give proof of the place of his birth. Suggest several other schemes that might be used in classifying people as they pass on the street, and in each case state what must be done to carry out the scheme.

A wise basis of classification important. It is very important that a correct basis of classification shall be chosen, or else useless work will be done. For example,

FIGS. 13 and 14. The child classifies the rocks according to their size; the geologist according to the materials of which they are composed.

a librarian wishes to classify a collection of books so that they will be most useful to the readers who come to the library. He might classify them according to color, size, or the material from which the covers are made; but such a classification would not be well chosen, for it is clear that on any of these bases books would be thrown together which are very far apart in their real character. What would be a better basis of classification? Why?

Classification of outdoor objects. Take your stand out of doors and make a list of 20 different objects that you see, such as trees, rocks, clouds, houses, fences, birds, shrubs, automobiles, forests, yards, and sidewalks. You will notice that some of these things have been produced by nature, and others have been made by man. This suggests a good basis of classification. Classify as natural or artificial the objects you have listed.

Using the same list of objects, notice that some things are alive. These things may be classified as plants or animals. What is the difference between a plant and an animal? Give a good deal of careful thought to this question. What is the difference between a cow and a cabbage? How are they alike? Does a cow require food? So does a cabbage. Does a cow grow by means of the food it consumes? So does the cabbage. Where does the cow get its food? Where does the cabbage get its food?

Exercise 6. Make a list of 20 animals that you know. Make a list of 20 plants that you know. In what ways do the animals differ from the plants? In what ways are animals and plants alike?

The chronological order. Sometimes it is best to arrange facts or events in what is known as the chronological, or time, order; i.e., the order in which the events occurred in time. For example, to mention the names of Washington, McKinley, and Lincoln would be to arrange them in a wrong order; to speak of breakfast, supper, and dinner would be to place the words in a wrong order. Would it be proper to list them as supper, breakfast, and dinner?

Exercise 7. Mention the days of the week in chronological order; the months of the year; the presidents of the United States; six events which lead up to a national election. Think of a half-dozen other lists of acts or events that can be arranged chronologically.

The alphabetical order. Another method of arrangement which is frequently used by the scientist is the

alphabetical order. Sometimes this is the proper method, and again it may be unscientific to arrange material in this way. If the object is to arrange the matter in such a way that any item can be found quickly and easily, the alphabetical arrangement is the proper one. Thus a book is almost worthless for reference unless it has an alphabetical index; a dictionary that did not have this arrangement could not be used; a list of voters in a township should always be made in this way. The items on a list which is so made may be alphabetical only as far as their initial letters are concerned; but it is better to make the list strictly alphabetical as to all the letters.

Exercise 8. Arrange alphabetically the names of the pupils in your class; the months of the year; the presidents of the United States; the states of the Union; the officers of your state; a dozen occupations followed by the people in your town. Make at least six other alphabetical lists.

Tabulating facts. Many times the scientist finds that the meaning of his facts becomes clearer and that they are more easily remembered if they are tabulated; i.e., arranged in tables. These tables take whatever form the scientist may choose, and it is an excellent exercise for a pupil to use his ingenuity in inventing methods of representing a given series of facts. You will have many opportunities to do this as you pursue the work outlined in this book.

Using the dictionary. Most of the thinking and recording of the scientist is done in words, and if his understanding of the meaning of words is not exact, his thoughts

and records cannot be accurate and clear. You should, therefore, very early get into the habit of taking your dictionary and looking up the definitions of words, paying special attention to the meaning of the Greek or Latin words from which the given word is formed. Thus the word "zoölogy" is derived from two Greek words, *zoon*, meaning animal, and *logos*, a word or discourse, or story; hence zoölogy is the science which describes and classifies animals. The person who is well versed in this science is known as a "zoölogist."

FIG. 15. Using the dictionary will help you not only in science, but in all the other intellectual work that you do.

Exercise 10. Study in the dictionary and enter in your notebook the definitions of the following sciences: geography, biology, ornithology, zoölogy, mineralogy, chemistry, physics, geometry, trigonometry, astronomy, physiology, history, algebra, chronology.

What is the meaning of the Latin verb from which the word "science" is derived?

An exercise like the above with the dictionary, if thoroughly done, is laboratory work just as truly as is handling any other kind of apparatus. To remind you of the importance of using the dictionary, certain words in this book have been marked with a star (*). To look up these and other unfamiliar words in the dictionary and to

write them, with their meanings, in your notebook, will help you not only in your science work, but in all the other intellectual work that you do.

Accuracy necessary in the scientist. One writer has suggested that "talking about" a thing and the "science" of the thing are entirely different. Talk about a thing may be random, scrappy, fragmentary; much of it may be about things of which the speaker knows very little; it may consist of some statements he is sure of and of many statements which are guesses.

This loose method is not permitted to the scientist. He must make his observations carefully and must draw only the conclusions which his facts will justify. Why must the scientist do this? Because the scientist is not allowed to guess; he must know. You, as a young scientist, must therefore learn to observe accurately, in order that you may have correct facts on which to base your conclusions. You must learn to weigh and measure, because as long as you do not know whether an object that you are holding in your hands is 18 inches or a yard long and whether it weighs 10 pounds or 20 pounds, your observations will be little more than guesses. You must learn to use language with exactness, to keep a record of your observations, and to arrange your facts so that their meaning will be clear. You must draw only those conclusions that are supported by your facts, and if you would be a true scientist you must avoid drawing conclusions about subjects of which you have no knowledge. Every single fact we know of the world about us was learned in this way.

CHAPTER THREE

MATTER AND ITS FORMS

FIG. 16. Matter is anything that occupies space.

MUCH of the time of a scientist is occupied with a study of matter. What is matter? Does the word have a definite meaning to you? Usually matter is defined as " anything which occupies space " or " takes up room." Another definition is, " Matter is anything that has weight." It is known to us by means of one or more of the senses.

Matter distinguished from the immaterial. Matter should be distinguished from other things that are not matter. For example, a thought is not matter; it does not occupy space; we cannot feel or taste or see or hear a thought. We cannot weigh a thought or speak of its size or color. It is not material. We say it is immaterial.

A raindrop is a form of matter; it occupies space; it has size, form, and weight. It is material.

Exercise 1. Enter the names of the following in your notebook and classify them as matter or not matter; that

is, as material or immaterial: a snowball; a memory; the stars and stripes; "Old Glory"; hatred; patriotism; a precious piece of paper kept in Philadelphia known as the Declaration of Independence; a man, meaning his body; a man, meaning his character; brain; mind; the earth; the sun; son; tree; dream; honesty; iron; pleasure; air.

FIG. 17. The flag itself is material; the sentiments it inspires are immaterial.

Three forms of matter. When we study matter and classify it according to the form it assumes under different conditions, — such as a difference of temperature, — we find that it is gaseous, liquid, or solid. Thus, water is usually liquid; but if the temperature falls low enough it will become a solid, and if the temperature is raised high enough it will take the form of a gas. Air is usually a gas, but under conditions of extreme cold and great pressure it assumes the liquid form. Perhaps some members of the class have seen liquid air.

Exercise 2. Examine a piece of camphor gum. Is it a solid, a liquid, or a gas? Place it in an evaporating dish and gently heat it. What form does it now take? Continue the heating, taking care not to burn the camphor. What form does the camphor take? What becomes of the camphor? How do you know this? What form of camphor is it that enters your nose?

Exercise 3. Name 25 different forms of matter and classify them as gases, liquids, or solids.

Exercise 4. Make a list of substances that may be changed from the solid to the liquid or gaseous form.

A definition* is a statement showing what a word means or what a thing is. Can you define a solid? a liquid? a gas? If you cannot, look up these terms in the dictionary or in some book on physics and enter the definitions in your notebook.

Division of matter. All forms of matter may be divided into very minute* particles. A stone may be broken into pieces and finally crushed to very fine powder; the diamond may be reduced to dust; a piece of ice may be divided into particles so fine that they cannot be seen; a fox running through the wood leaves enough odorous particles along his pathway to enable the hound that pursues him to keep on his track.

Exercise 5. Dissolve a small amount of common salt in water. Taste the solution. Is the salt still there? Is it visible to your eye? Can it be recognized by your sense of taste? Add more water and continue to add it as long as you can clearly distinguish the taste of the salt. Think how very small must be the particles of the salt that are present in every part of the water.

FIG. 18. An evaporating dish.

Exercise 6. Dissolve a small amount of dye in a large vessel of water. Are the particles of dye present in all parts of the water?

Exercise 7. Take a round-bottomed liter flask, — any bottle will do, — place in the flask a small piece (one

quarter as large as a kernel of wheat) of solid iodin. Cork the flask. Hold it over a flame and heat it very gently. Soon the solid iodin has changed to a beautiful purple gas. The particles of the solid have been driven far apart and have been separated from each other, and the gas now occupies every portion of the flask.

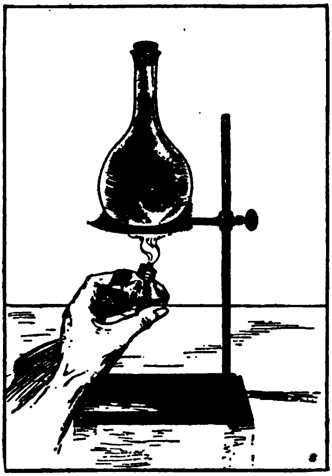


FIG. 19. The molecules of iodin are driven apart by the heat.

Matter composed of particles called molecules. An experiment* is a question put to Nature. The answers given back to us are always true and we can rely upon them; the only difficulty comes in interpreting the replies. What replies did we receive to the questions we have been asking about matter, and how shall we interpret them?

Scientists interpret these experiments to mean that matter is composed of very small particles, — particles so minute that we cannot see them with the most powerful microscope. These small particles of matter they call molecules. Thus they speak of the molecules of water, of gold, or of salt.

The smallest particle into which matter can be divided without changing its nature is called a molecule.

FIG. 20. In a solid the molecules are confined in their places; in a liquid they hold together but move easily over each other; in a gas they fly apart.

A group of molecules make a mass of matter.

The difference between solids, liquids, and gases. Turn now to your notebook and read the definitions you have written of a solid, a liquid, and a gas. What is the difference in the condition of the molecules in these three states of matter? If you think over this question carefully, you will come to the following conclusions:

(1) In a solid the molecules are held firmly together and are confined quite closely to their places. They cannot move about to any great extent or slide on each other. A solid, therefore, keeps the same form.

(2) In a liquid the molecules hold together less firmly, and they can slip easily over each other. For this reason, liquids flow about and are able to take any shape. A liquid will always take the shape of the vessel into which it is placed, except that the top remains flat.

(3) In a gas the molecules are entirely separate and instead of holding together fly apart as widely as possible. The walls of a blown-up football are kept pushed outward by the ceaseless hammering of millions of air mole-

cules that beat against them, and the pressure in a boiler is caused by the steam molecules striking against its sides.

Study again the experiments you have performed and explain what the molecules do in each one. Can you think of any substances that are midway between a solid and a liquid in their nature?

A closing thought. We will close this lesson by recalling the idea that everything in this world is either material or immaterial, and that matter is composed of an infinite number of little parts, called molecules. In a stone the molecules are prisoners chained to their places; in a brook they are an army, sliding and rolling over each other on their way to the sea; in the air they are a multitude of tiny particles, dancing and shooting about. Matter is a wonderful thing, and many interesting experiments can be done with it.

CHAPTER FOUR

SOME PROPERTIES OF MATTER

FIG. 21. "I am the daughter of Earth and Water,
And the nurseling of the sky;
I pass thro' the pores of ocean and shores;
I *change*, but I cannot die." — SHELLEY: *The Cloud.*

IN the last chapter we learned that matter is anything that occupies space. This definition tells us what matter is, but it does not tell us what it is like or what we can do with it. Since the scientist spends much of his time working with matter, we shall in this chapter investigate some of its properties. This is only another way of saying that we shall try to find out what we can and what we cannot do with it.

Impenetrability of matter. Impenetrability* is a property of all matter. Exactly what is meant by the term "impenetrability" will be made clear by a few experiments:

Exercise 1. Have a boy stand upon the floor and with a piece of crayon draw a circle just inclosing his feet. Now let a second boy try to occupy this circle with the first one. Can two boys occupy the same space at the same time?

This may seem to be a foolish question, and you will say, "Of course two boys cannot occupy the same space at the same time." That is true, but let us see if you are as ready to make this assertion about some things besides boys.

Exercise 2. Take a tumbler and a dish of water. Hold the tumbler bottom up and press its mouth down deep into the water. What is in the tumbler when it is first placed in the water? Does the water rise and fill the glass? Why?

The answer is the same as before. The air and the water cannot occupy the same space at the same time.

Exercise 3. Tip the tumbler to one side while still pressing down upon it. What happens? Be sure to notice that two things happen. Which happens first?

Exercise 4. Stand a good-sized bottle or jug upright, and pour water into it rapidly. What happens? Why? When the jug is full of water, turn it over with the mouth down. What two things happen? Which happens first?

Exercise 5. Drive a nail into a pine board. Do the nail and the wood occupy the same space at the same time, or does the nail push aside the wood in order to make

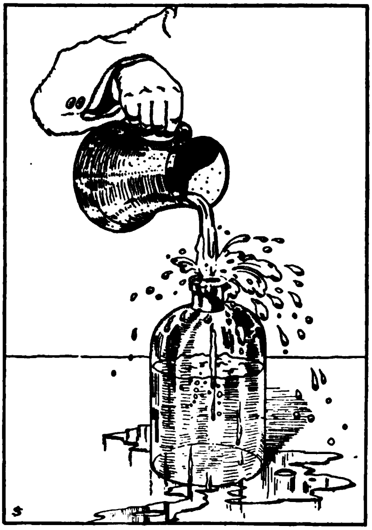


FIG. 22. Why does not the water enter the bottle?

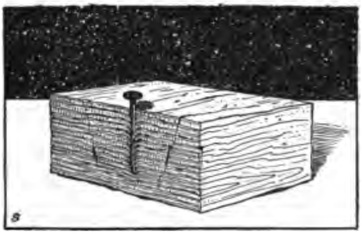


FIG. 23. The nail and the wood cannot occupy the same space at the same time.

a place for itself? Draw out the nail and see if the wood has been pushed aside. Try the same experiment in water. Account for the difference in results.

Thus you find it is true that no two bodies or substances can occupy the same space at the same time. This fact is true of all forms of matter, and this property or quality of matter is known as impenetrability.

Exercise 6. Raise a window about three inches at the bottom and with a smoke paper[1] see whether the air is passing out of the room. Do you see why opening a window oftentimes fails to accomplish its purpose? Could pure air enter the room until some of the air already in the room had passed out? Lower the window from the top without closing the opening at the bottom, and test the flow of the air at both places. Two openings are better than one if we wish to get fresh air into a room.

Exercise 7. Take a tall, slim bottle or tumbler and fill it partly full of water. Mark the top of the water very accurately by pasting a strip of paper even with it. Then slowly add salt or sugar, allowing it to dissolve in the water. Can you add a considerable amount of salt without causing the water to rise above the mark?

[1] A good smoke paper may be had by rolling a piece of brown wrapping paper into a compact roll. This is lighted, and when burning freely the flame is extinguished. A piece of filter paper or other soft paper soaked in a solution of potassium nitrate makes an excellent smoke paper.

In this case the salt and the water seem to occupy the same space at the same time; but, suppose you had a bushel basket full of apples, could you not still add a large number of marbles without filling the basket more than full? So the case of the sugar dissolved in water is explained by saying that there are spaces between molecules and that the molecules of the sugar occupy the spaces between the molecules of the water. Two molecules cannot be in the same place at the same time any more than two boys or two marbles can be in the same place at the same time.

Malleability. Impenetrability is a property of all matter, but certain other properties may be possessed by some substances and not by others. Such a property is malleability.* Perform the following experiment and you will understand the meaning of the term:

Exercise 8. Place a piece of lead on some flat, hard surface, as an anvil, and hammer it. It spreads out under the hammer without being broken. It is evident that the molecules of the lead change their relative positions during this process. Under the force exerted on them by the blows of the hammer they slip on each other to some extent.

Metals are extensively used in industry,* and one great advantage that many of them have over wood and stone is that they are malleable.* Of all the metals platinum and gold are the most malleable; gold can be rolled into leaves so thin that it would take 300,000 of them to make the thickness of one inch. Tin also can be rolled quite thin, as you may see for yourself by ex-

amining a piece of tin foil. Iron is quite malleable when heated, and thousands of men work in great mills, rolling it into rails, girders for buildings and bridges, sheets for roofs and tanks, and dozens of other forms. Copper is more malleable at ordinary temperature than when it is heated.

Exercise 9. Test various substances as to malleability: a pin, a nail, a penny, a nickel, shot, a pebble, a piece of cold glass. Record the results of these tests in your notebook.

Ductility. When a solid can be drawn out into a fine thread or wire, it is said to be ductile,* and this property of a solid is known as ductility. Iron, copper, and many other metals are ductile.

Exercise 10. Heat a piece of glass tubing until it is soft and flexible. Then draw the ends of the tubing away from each other; the heated part will be drawn out into thin threads. To prove that these threads are still tubes, place one end in colored water or ink, and notice that the liquid rises inside.

Platinum and gold can be drawn into wires as fine as a spider's web, — wires so small that they can scarcely be seen without a magnifying glass. It is a remarkable fact that the strength of some metals is increased by drawing them out into wires, and for this reason a drawn wire is stronger than an ordinary piece of the metal of the same thickness. Cables made by twisting iron wires together will support a much greater weight than solid iron rods of the same size, and such cables are used in the building of suspension bridges where great strength

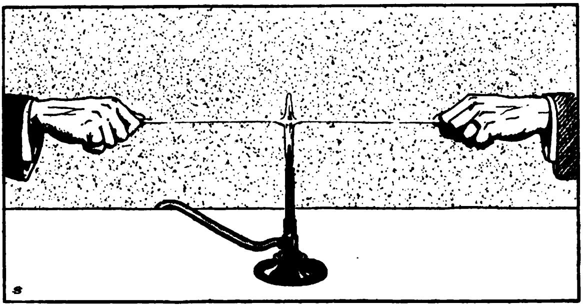


FIG. 24. After glass has been heated, it can be drawn out into fine threads.

is required. The great Suspension Bridge at Niagara Falls is an example of a bridge of this kind.

Brittleness. Substances that are not malleable or ductile will crumble into small pieces when struck with a hammer. Examples of such substances are cold glass, almost all rocks, ivory, chalk, ice, an eggshell. This property is called brittleness, and substances possessing it are said to be brittle. Find other examples of brittle substances.

Elasticity. Certain substances return to their original form when this has been changed by some force applied to them. By this return to the original form the molecules come back to the places they occupied before the change. This property is called elasticity, and substances possessing it are said to be elastic.

Exercise 11. Stretch a rubber band or compress a rubber ball and watch it return to its original form. Test various articles as to elasticity: wood, ivory, gum, whalebone, copper, iron, lead, steel, a drawn-out glass tube or a thin

sheet of glass. Bend each one and notice what happens when the force is removed.

What happens when moist snow is pressed between the hands? when a rubber ball is thrown against the sidewalk?

Flexibility. Elasticity is to be carefully distinguished from another property which a substance shows when it bends but fails to return to its original form or size. In this latter case the substance is said to be flexible,* or to possess the property of flexibility. Is a cord elastic? Is it flexible? Which of the substances tested in Exercise 11 are flexible?

Hardness. One solid is said to be harder than another when it will scratch or make a mark upon the other substance. The diamond will scratch glass because it is harder than glass; a knife blade will scratch a piece of limestone because it is harder than limestone; the knife blade will not scratch a piece of quartz, because it is softer than the quartz.

Why does the ax cut the wood instead of the wood cutting the ax? Is a file or a saw made of harder material? State some of the disadvantages man would be under if all solids possessed the property of hardness in equal degree.

Indestructibility. Matter cannot be destroyed; we may change its form or even make it invisible, but all matter possesses the property of indestructibility.

Exercise 12. Into a tin cup — or better, an evaporating dish — containing water, place a small amount of sugar.[1]

[1] Copper sulfate may be used instead of sugar.

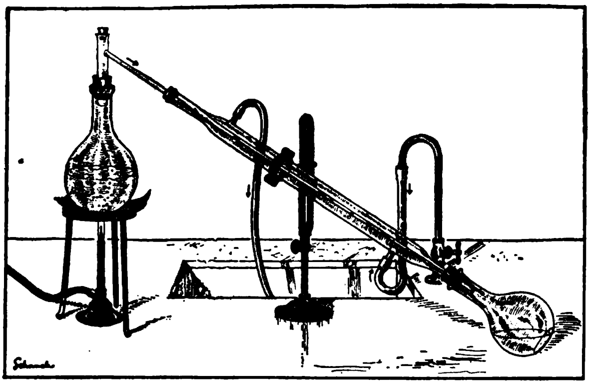


FIG. 25. A condenser of the kind that chemists use in their laboratories. Explain how it works and for what purpose it is used.

The sugar disappears from sight. Has it been destroyed? Taste the solution and notice that it has the well-known sweet taste of sugar.

Place the dish on the stove or over a flame and with gentle heat boil away the water until the sugar is dry. Do not let the sugar burn. Now taste the solid and convince yourself that you have the sugar back again.

In the experiment just made, it might seem that the water had been destroyed. It certainly became invisible and disappeared. Was it destroyed? By holding a cold glass over the dish you can prove that the water is escaping as a gas into the air, and if a distilling apparatus is at hand, all the water which escapes in the form of steam may be condensed and recovered.

The law of the conservation of matter. Thus it is true for all kinds of matter that we may change its form but we cannot destroy it. We may put a stick of

wood into the fire and it is wonderfully changed, but the identical matter that formerly existed in the wood either remains in the ashes or goes up the chimney in smoke or invisible gas. Matter can be neither created nor destroyed. In the universe there exists today exactly the same amount of matter that existed in it millions of years ago. This is known as the great Law of the Conservation* of Matter.

CHAPTER FIVE

CHANGES IN MATTER

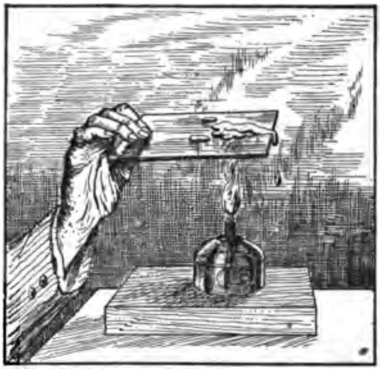


FIG. 26. After wax is melted it is still wax; the change in it is a physical change, and its identity is not destroyed.

THE observant person is impressed by the fact that changes are going on all about him. The wood that is placed in the stove is changed into the gases that go up the chimney and the ashes that remain in the stove. The sour milk and the soda that are used in the making of griddle cakes has each its own peculiar taste, but in the cooking process these two substances evidently are changed, for we do not detect* either when we eat the cakes. A bright knife blade which is carelessly left in moist air changes to a brown, crumbling substance that we call "rust." The materials that a tree draws from the earth are changed into flowers or fruits, and the food that a bird or a sheep eats becomes feathers or wool. Matter cannot be destroyed, but great changes in matter can easily be brought about.

Two kinds of changes in matter. Sometimes a change in matter is only temporary* and the substance can be made to return to its former condition, as when ice is formed from water, or steam from water, or water from steam. Other examples of this kind of change are

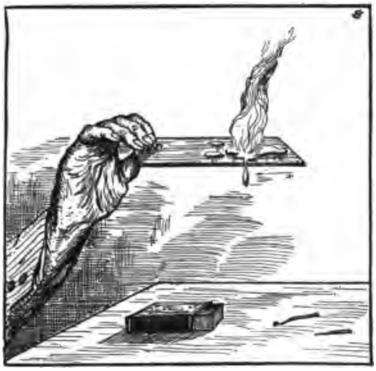


FIG. 27. But after wax has been burned it is no longer wax; it has undergone a chemical change and its identity is lost.

seen in: a piece of iron which has been heated and then cooled; a piece of wood that is bent and then allowed to straighten out; a piece of wax that is melted and then hardens; a piece of iron which is attracted by a magnet and then has the power to attract other pieces of iron. In these cases the substances have not lost those qualities by which we describe or identify them. After being heated iron is still iron, after being bent wood is still wood, and after being melted wax is still wax.

Changes of this kind are known as physical changes. All such changes are studied in the science known as physics.

Sometimes permanent* changes take place in matter and the substances never return to their former condition, as when iron rusts or a piece of wood decays. Other examples of such changes are: the decay of fruits and vegetables; the souring of milk; cider changing into vinegar; the digestion of food; the burning of wood or coal. In all such cases the substances have lost their former qualities and have taken on new ones; they have been broken up and new substances have been formed from them. Such alterations* or changes are called

chemical changes, and they are studied in the science known as chemistry. In practical life physics and chemistry are closely related; the engineer sets going a chemical process when he throws coal into the fire and a physical process when he turns on the steam.

Exercise 1. Take a third of a test tubeful of granulated sugar. Notice that the sugar is a white solid and that it has its own peculiar taste. Heat it gradually by placing the test tube in or near the flame of an alcohol lamp or Bunsen burner. It changes color and dissolves. Presently it becomes black. Taste it. A change has taken place. Charcoal, or carbon, has been produced. What kind of change have we in this case?

Atoms. How shall we explain what has happened in the test tube? A chemical change has taken place, and the chemist explains it by supposing that molecules are made of still smaller particles which are called atoms, and that when the sugar is heated the molecules are broken up and new substances are built from the atoms that were in them. One of these new substances is the carbon that remains in the test tube.

An atom is the smallest particle into which matter is divided in chemical changes.

A molecule is made up of two or more atoms. Would it be correct to speak of an atom of sugar?

Chemistry is the science of the atom and of how atoms combine with each other to form molecules.

Exercise 2. Take two tumblers or beaker glasses of the same size. Set them on a table at least a yard apart. Rinse one with ammonium hydroxid and the other with hydro-

FIG. 28. The molecules of the two invisible gases are broken up, and the atoms in them are used to build a white solid.

chloric acid. Cover one with a paper and bring it to the mouth of the other. Withdraw the paper. What takes place?

The scientist believes that the molecules of these two gases have been broken up and the atoms in them used to build the white solid (ammonium chlorid) that has been formed.

Exercise 3. Chew thoroughly some kernels of wheat (puffed wheat will do) and hold them in the mouth for some time. Observe carefully. Do you detect, after a while, a sweet taste?

The explanation is that the saliva has changed the starch in the wheat to sugar. The starch molecules have been broken up and sugar molecules have been formed.

Exercise 4. With a pair of forceps hold a piece of magnesium ribbon in a flame. What takes place?

The ribbon burns, and in the process the silvery and malleable metal, magnesium, is changed to a white and very brittle substance known as magnesium oxid. What kind of change is this?

Elements. Many substances can be broken up into simpler ones, but there are some substances that cannot

be so divided. For example, the chemist cannot get from a piece of pure gold anything but gold, or from pure silver anything but silver. The atoms in the molecules of gold and silver are all alike, and it is impossible to divide the molecules into substances of different kinds. A substance that has in it only one kind of atom is called an elementary substance, or an element. On page 371 a table of some of the more common elements is given. About 85 elements are now known.

Compounds. When the molecules of a substance are composed of two or more atoms that are different from each other, we have a compound substance, or a compound. If we pass electricity through water,[1] we find that the water decomposes* into two substances, oxygen and hydrogen, and we therefore say that water is not an element but a compound of hydrogen and oxygen.

The number of elementary substances in the world is very small as compared to the number of compounds. When we decompose and study the thousands of known compounds, we find only 85 different kinds of atoms in them all. Many of the elements are so rare as to be of only passing interest to the practical man. Hence the ordinary course in chemistry includes the study of only about 35 elements and the compounds which are formed from them.

Chemical symbols. Chemists have devised a system of shorthand writing by which they use brief symbols for the elements instead of writing out the full names. Generally the symbol is an abbreviation of the English

[1] A little sulfuric acid is added to the water to conduct the electricity.

or Latin name of the element. For example, the symbol for oxygen is O; for carbon, C; for calcium, Ca; for iron, Fe (Latin, *ferrum*); and for gold, Au (Latin, *aurum*).

Chemical formulas. Chemists have also a brief and simple way of indicating the elements and the number of atoms in chemical compounds. They write one after another the symbols of the elements in the molecule of the compound; and with small subscript* figures they show the number of each kind of atoms. Thus H_2O (read this formula "H-two-O") stands for 1 molecule of water, which contains 3 atoms, — 2 of hydrogen and 1 of oxygen. H_2SO_4 (H-two-S-O-four) stands for 1 molecule of sulfuric acid, containing 7 atoms, — 2 of hydrogen, 1 of sulfur, and 4 of oxygen. $C_{12}H_{22}O_{11}$ (C-twelve-H-twenty-two-O-eleven) stands for a molecule of common sugar with 45 atoms, — 12 atoms of carbon, 22 of hydrogen, and 11 of oxygen. In a similar way the composition of all chemical compounds may be represented by chemical formulas.

Some facts to remember. Matter undergoes physical and chemical changes. In physical changes the identity of the substances is not destroyed; the molecules are not broken up and the substances can return to their original form. In chemical changes the identity of the substances is lost; they are decomposed and from the materials of which they were composed new and different substances are formed. In such changes the molecules of the substance are broken to pieces and the atoms in them are used to build new and different molecules.

All cases of chemical change follow the law of the conservation of matter. When the molecules are broken up, the atoms in them are not destroyed; they are only separated from each other, and they at once unite with other atoms to form new substances. Every atom that was in the original substances will be found in the new substances that are formed.

CHAPTER SIX

OXYGEN: THE ACTIVE ELEMENT

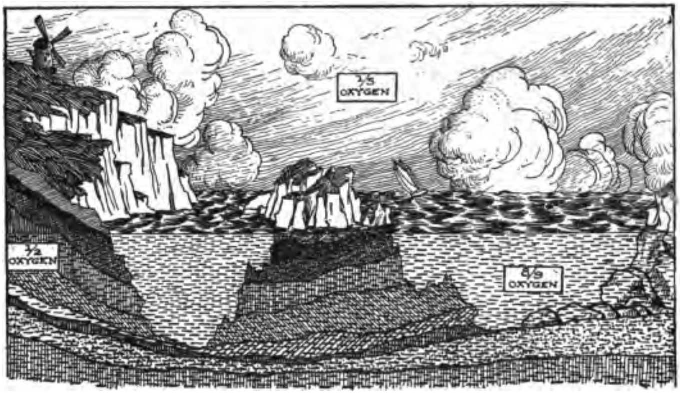


FIG. 29. By weight, oxygen constitutes one half of the earth's crust, eight ninths of water, and about one fifth of the atmosphere.

OXYGEN is by far the most abundant of the elements. By weight, it constitutes one half of the crust of the earth, eight ninths of water, and about one fifth of the atmosphere. Not only is oxygen the most abundant element, but it is also the most active in forming compounds; its atoms unite with the atoms of other elements to form substances of many different kinds. It also enters into the composition of nearly all the substances to be found in plants and animals. This latter fact will be more thoroughly studied in a later chapter.

Preparing oxygen. Oxygen may be obtained by heating potassium chlorate or manganese dioxid or, better still, a mixture of the two. Both these substances contain oxygen, and when they are heated their mole-

cules are broken up and the oxygen in them is set free. The process is as follows:

Exercise 1. Powder a small quantity of pure potassium chlorate and mix it with one fourth as much manganese dioxid (black oxid of manganese). Keep the mixture perfectly dry and free from dust or other foreign matter. Fill an ignition tube about one third full of the mixture.[1] Close the tube with a cork through which passes a small delivery tube (Fig. 30). Support the tube in a slanting position and apply heat. Heat the upper part of the mixture first and regulate the heat so that the gas will be given off at a uniform* rate. The gas can be collected in bottles filled with water and inverted in a vessel of water (Fig. 38). Fill several bottles with the gas. Close the bottles with a glass plate or cork and stand them upright. Keep them stoppered or covered. Why? Remove the delivery tube from the water before the lamp is taken away from under the test tube.

Oxygen is a transparent,* colorless, tasteless, odorless gas. If you remember that the air you have been using all your life contains oxygen, you will know that the last four statements are true.

Exercise 2. Light a pine stick and let it burn until a bright coal of fire will remain when the flame is blown out. Thrust the glowing stick into one of the bottles of oxygen. Notice that the gas itself does not burn, but the stick immediately bursts into a very bright flame.

[1] An ignition tube is made of hard annealed glass, which will not melt or crack except under very intense heat. An ordinary test tube may be used in this experiment if care is taken in heating it. A copper or iron retort may be used to advantage when a large amount of oxygen is desired.

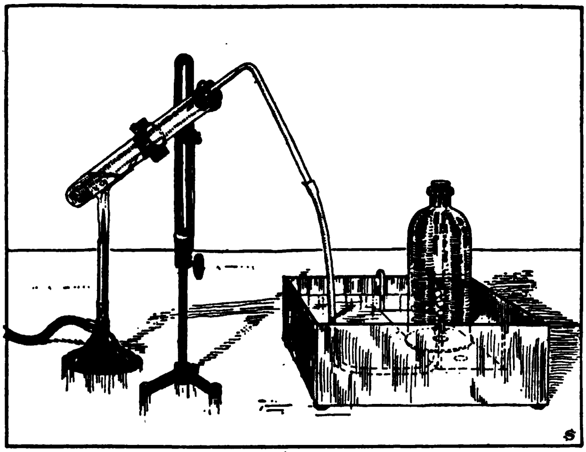


FIG. 30. Preparing oxygen from one of its compounds.

Two things are to be noticed: first, the gas itself does not burn; secondly, it causes the stick to burn, or, as the chemist would say, it supports combustion.

Exercise 3. Fasten a piece of charcoal — a piece made from bark is best — to a wire and, after it has been ignited, lower it into a jar of oxygen. Brilliant combustion will take place and will continue until all of either the oxygen or the bark is consumed (Fig. 31).

After trying the above experiment, ask yourself two or three questions: What did you put into the bottle? Remember that both charcoal (or carbon, which is another name for it) and oxygen are elements. What do the atoms of oxygen and carbon do when the charcoal burns? What does the bottle contain at the close of the experiment? Evidently it must be a com-

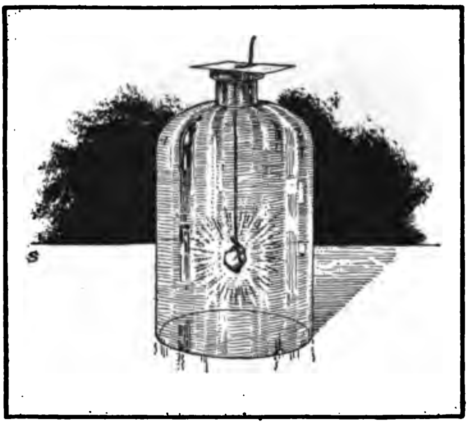


FIG. 31. Charcoal burning in a bottle of oxygen.

pound of carbon and oxygen. It is, in fact, the well-known gas called carbon dioxid.

$$C + O_2 \rightarrow CO_2$$
carbon + oxygen produces carbon dioxid

Exercise 4. Take a short piece of crayon and with a knife cut out a small cup. Attach the cup to a wire and you have a deflagrating* spoon. Load it with sulfur, ignite the sulfur, and lower it into a jar of oxygen. Hold it until the sulfur is all consumed. What was in the jar at the beginning? What did you put into it? What is in the jar at the close of the experiment? Cautiously smell the gas in the jar and compare it with the odor obtained from burning sulfur. The two gases are identical.*

You have added a solid to a gas and obtained another gas.

$$S + O_2 \rightarrow SO_2$$
sulfur + oxygen produces sulfur dioxid

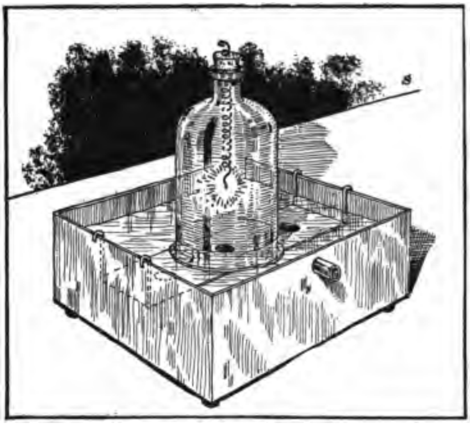


FIG. 32. Even iron will burn in a jar of oxygen.

Exercise 5. Take a piece of iron picture-wire.[1] It should be long enough to reach to the bottom of the jar containing oxygen. Heat one end of it by placing it in a flame for an instant, and then dip it into some sulfur. The sulfur will adhere to the iron and by burning will raise the temperature of the iron to what is known as its "kindling point." Now quickly introduce the hot iron into a jar of oxygen. It will burn brilliantly, throwing off bright, glowing sparks, and the iron will gradually be consumed (Fig. 32). What kind of substance is formed when the iron is burned? Have you seen this substance before?

Oxygen a very active element. These experiments show the most characteristic property of oxygen. It is an extremely active element, and the experiments you have performed should suggest to your mind some

[1] A watch spring which has been heated and straightened may be used in this experiment, but the picture cord is better.

interesting queries. If the atmosphere were composed entirely of oxygen, would not the stove burn as well as the wood in it? Why does not this happen now if one fifth of the air is pure oxygen? We shall find an answer to the last question when we study the nitrogen of the air.

Compounds of oxygen called oxids. Oxygen unites to form compounds with all the known elements except a very few. These compounds are called oxids. Thus, when the iron burned in the oxygen, or was oxidized, iron oxid was the result, a compound more familiarly known as iron rust. The metal calcium and oxygen combine to form calcium oxid, commonly known as lime; silicon with oxygen forms silicon dioxid, known as silica, or sand, and so on.

The meaning of "id" in chemistry. Chemical substances that have names ending in id contain elements that are mentioned in the name and no others. Thus sodium chlorid (common salt) contains only sodium and chlorin; iron sulfid, only iron and sulfur; magnesium oxid, no element but magnesium and oxygen.

What elements do the following compounds contain: mercuric oxid, gold chlorid, hydrogen sulfid, potassium iodid, iron oxid, carbon dioxid, sulfur dioxid?

Slow oxidation. Oxygen oftentimes unites so slowly and gradually with other elements that neither light nor intense heat is produced. These, however, are none the less cases of oxidation, or combustion, as it is ordinarily called, and the compounds are the same whether the action takes place slowly or rapidly. A house produces as much heat, in the aggregate, if it decays by slow

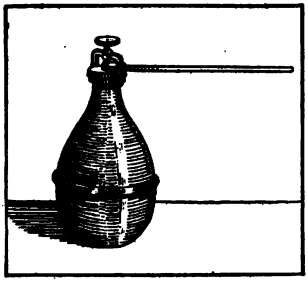


FIG. 33. A retort for the manufacture of oxygen.

oxidation through many years as it does if it is consumed by fire in an hour or two. Cases of slow oxidation are all about us, and if you are wide awake you will be able to find many of them. Explain the rusting knife blade; the ink which is first pale and afterward bright and distinct; the wood rotting in the forest; why we galvanize our fences and roofs and paint our bridges and houses; and why we constantly fill our lungs with air.

Oxidation an important process. How do we obtain heat to warm our houses and power to run our machinery? Usually by oxidizing wood and coal. How do we light our houses? By oxidizing gas or kerosene, or with electricity that is made by machinery run by burning wood or coal. What happens when gasoline explodes in the engine of an automobile? The gasoline suddenly unites with the oxygen of the air which has been drawn into the cylinders.

A furnace is an oxidizing machine; an engine is an oxidizing machine; and man and all other animals are oxidizing machines. By heat secured from the process of oxidation metals are melted; by power secured from the same process buildings are refrigerated and water is frozen to ice. Human life and all human activities depend upon oxidation; without oxygen our lives and our activities would cease.

CHAPTER SEVEN

HYDROGEN AND ITS COMPOUNDS

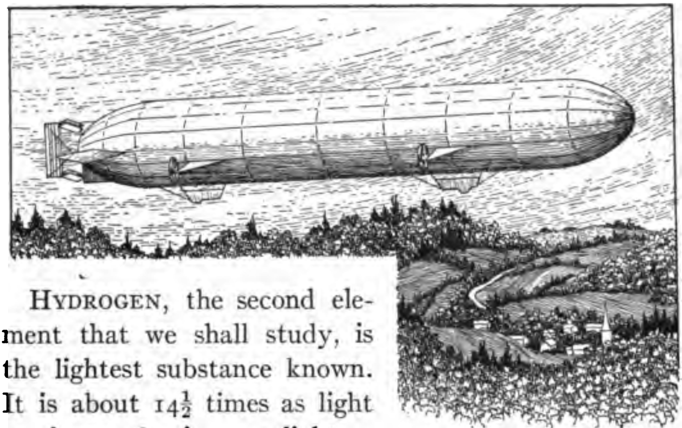


FIG. 34. Because of its lightness, hydrogen is used in filling airships and balloons.

HYDROGEN, the second element that we shall study, is the lightest substance known. It is about $14\frac{1}{2}$ times as light as air, 11,160 times as light as water, and 151,700 times as light as the metal mercury. It enters into the composition of all plants and animals and forms part of wood, coal, and petroleum; but the great store of hydrogen in the world is in the vast amounts of water which are found on the surface of the earth. Hydrogen occurs in a free state in the gases from some volcanoes and natural-gas wells, and in the atmosphere of the sun and of some fixed stars. Because of its lightness, it is used for filling airships and balloons.

Exercise 1. Place a few scraps of zinc in a good-sized test tube. Fill the test tube half full of water and pour into it a few drops of hydrochloric or sulfuric acid. A gas will be seen bubbling up through the liquid and escaping into the air. This gas is hydrogen.

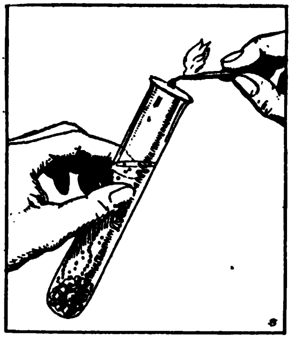


FIG. 35. Hold the test tube away from the body and with its mouth pointing away from the face.

Bring a lighted match to the mouth of the tube and a slight explosion will take place.[1]

Exercise 2. Provide the tube with a tightly fitting cork and a delivery tube. After all the air has been forced out, light the gas.[2] The hydrogen burns quietly with a transparent blue flame.

Caution! Be very careful not to light the gas until all the air has been expelled from the tube, as a mixture of air and hydrogen forms a combination that, when ignited, will explode with very great violence.

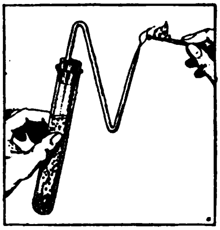


FIG. 36. *Be careful not to light the gas until all the air has been expelled from the tube!*

Exercise 3. Hold a tumbler or receiver that is both dry and cold over the flame of burning hydrogen and notice the water that condenses upon the cool surface. What is uniting with the hydrogen to cause it to burn (Fig. 37)? What evidence does this afford as to the composition of water?

[1] In this and other experiments the test tube may be held in the hand, provided it is held with the hand extended from the body and the mouth of the test tube pointing away from the face of the experimenter.

[2] To determine when the escaping hydrogen is free from air, fill a small test tube with the gas as directed in Exercise 4. Then close the mouth of the test tube with the thumb, carry it a short distance from the generator, and holding it mouth down bring a lighted match or taper to the mouth of the tube. If only a slight explosion follows, the gas may be lighted.

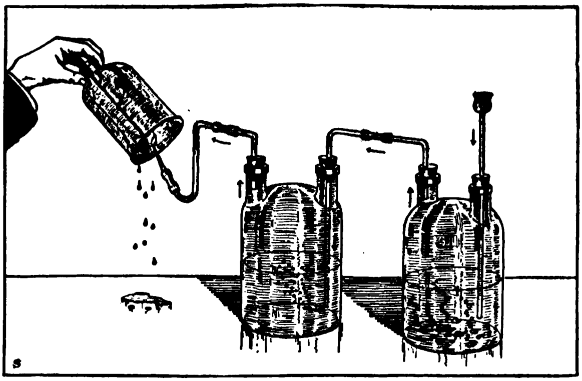


FIG. 37. Condensing water that is formed from burning hydrogen.

Exercise 4. Attach a piece of rubber to the end of the delivery tube and collect the gas over water as the oxygen was collected. Fill several vessels in this way.

Exercise 5. Carefully and slowly, holding it with its mouth downward, lift a tube filled with the gas. (Why must the mouth be kept down?) Now light a taper and push it up into the gas (Fig. 39). Two things will happen: (1) The gas will be ignited at the mouth of the tube and will burn with great heat but with an almost invisible blue flame, and (2) the flame of the taper will be extinguished. If the taper is withdrawn, it will be relighted at the mouth of the tube. The lighting and relighting may be repeated several times.

This experiment has shown that hydrogen is a gas which will burn but will not support combustion in other things.

Exercise 6. Fill some soap bubbles with hydrogen by fitting a clay pipe into the rubber delivery tube from which

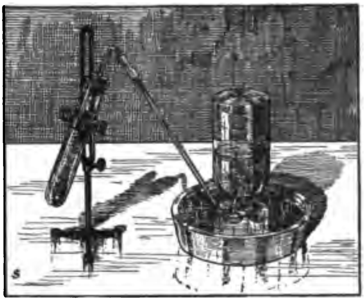


FIG. 38. Collecting hydrogen.

hydrogen is being produced.[1] After a bubble has been set entirely free from the generator, bring a lighted taper to it. Explain what happens.

Comparison of hydrogen and oxygen. Some of the important differences between hydrogen and oxygen are the following:

HYDROGEN	OXYGEN
1. It is lighter than air.	1. It is heavier than air.
2. It is combustible.	2. It is not combustible.
3. It will not support combustion.	3. It supports combustion in a most remarkable way.

If, now, we carry the comparison further and contrast the properties* of these two elements with the properties of the water which is formed when they unite, we catch a glimpse of a very important and far-reaching chemical principle. This principle will be discussed in the next paragraph.

Compounds different from the elements that compose them. It is a remarkable fact that compounds are usually utterly unlike the elements of which they are made. Thus, the properties of water are totally different from the properties of the oxygen and hydrogen from which

[1] A little glycerin added to the soapsuds will make the bubbles tougher.

it is made; yellow sulfur and liquid mercury form a red powder known as vermilion; carbon, a solid, combined with nitrogen and hydrogen, two gases, forms the deadly prussic acid; two solids, black carbon and yellow sulfur, when chemically united form a transparent liquid known as carbon disulfid; the poisonous and highly offensive chlorin gas, which has been extensively used as a weapon in modern warfare, combines with sodium, a metal, to form common salt; and the limpid, liquid oil of turpentine is composed of the black solid, carbon, and the gas, hydrogen. Some of the compounds mentioned may be found in the chemical laboratory, and the last one may be the subject of an interesting experiment.

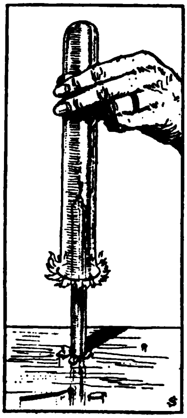
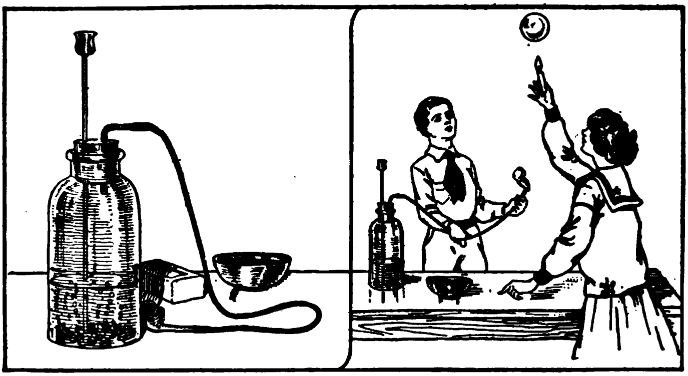


FIG. 39. Hydrogen burns but will not support combustion.

A study of turpentine. With very simple apparatus, oil of turpentine can be broken into its elements, which are very different from itself. This is done in Exercise 7. The object of this exercise is in part to determine the composition of turpentine, but more especially to illustrate the fact that whenever two or more elements unite by chemical action, both lose the properties they originally possessed and form a compound having entirely different properties.

Exercise 7. Obtain a small quantity of turpentine, — five cents' worth, — such as is used in mixing paint. Notice its clearness, transparency, and odor. It is a liquid, easily



Figs. 40 and 41.

changing to a gas when heated. Fill a common alcohol lamp with it. A small bottle with a cotton wick drawn through the cork will do.

When the oil has filled the wick, light the lamp and hold over it a glass tumbler. The glass will be filled with a great quantity of black solid. This is carbon, which must have come from the turpentine.

Hydrogen in the turpentine. The only other element contained in turpentine is hydrogen. The proof of this statement would not be within the reach of the beginner in chemistry, and he will have to take the word of the experienced chemist. Turpentine is a compound of carbon and hydrogen. Its composition is given in the formula $C_{10}H_{16}$.

Exercise 8. Make a list of the properties of carbon, hydrogen, and turpentine. Do the carbon and hydrogen experience a total loss of their original properties when they unite chemically to form turpentine?

Three classes of compounds. Most chemical compounds can be classified into one or the other of three groups. These groups are known by the names acids, bases, and salts. As acids are the compounds from which hydrogen must be obtained, this class is studied in connection with that element.

Acids. Acids are constantly used by the chemist, and are of great importance in many industrial processes. All acids contain hydrogen, which is set free when the acid comes in contact with a metal. Let us now investigate this very important class of substances.

Exercise 9. To a test tube half full of water add not more than six drops of hydrochloric acid. Mix the acid and water together and then lift out a small drop of the solution with a glass rod and touch it to the tongue.[1] Could you describe the taste of the hydrochloric acid? Does it have a sour taste? The taste is due to the hydrogen which is set free when the acid is dissolved in water.

Exercise 10. Put a little piece of blue litmus paper into the mixture. What happens? This is the usual test for any acid.

Exercise 11. Now add more of the acid to the water solution and into this drop a small scrap of sheet zinc or magnesium. Notice the bubbles of gas which rise from the surface of the zinc to the surface of the water. Bring a lighted match to the mouth of the test tube. A slight explosion takes place. The chemist recognizes this as a sign that hydrogen has been produced (page 52).

[1] It is not safe to taste chemicals in the laboratory except when advised to do so by some one who has knowledge of the chemical in question.

The chemist reasons that since zinc is an element composed of that metal and nothing else, the hydrogen must have come from the hydrochloric acid. His record of what happened in the above experiment is as follows:

$$\underset{\text{zinc}}{Zn} + \underset{\text{hydrochloric acid}}{2\,HCl} \underset{\text{produces}}{\longrightarrow} \underset{\text{zinc-chlorid}}{ZnCl_2} + \underset{\text{hydrogen}}{H_2}$$

The zinc unites with the chlorin of the acid, thus taking the place of the hydrogen and setting it free.

Exercise 12. Repeat the last three exercises, but use sulfuric acid instead of hydrochloric acid. For the first two exercises use not more than three drops of sulfuric acid, and for the last exercise nine or ten drops. Make a record of these tests and the results.

Exercise 13. Repeat the three tests, but use strong vinegar, which contains a well-known acid called acetic acid. Record your results.

Properties of acids. These three substances, hydrochloric acid, sulfuric acid, and vinegar, are representatives of the class of chemical compounds called acids, of which there is a very large number. The properties of an acid are:

1. It is sour to the taste.
2. It turns blue litmus paper red.
3. It contains hydrogen, which can be set free by the action of a metal.

In the majority of cases the litmus-paper test is the only one that need be made in order to detect an acid.

Exercise 14. Test with blue litmus paper various substances to be found about the laboratory and at home, such

as lemon juice, sour milk, saliva, the pulp from a gooseberry, or the juice of rhubarb.

Exercise 15. Dig up some soil from a field or garden and make a compact moist ball of it. Split it open and place a piece of blue litmus paper in it, leaving the paper there for a few minutes. Many crops do not grow well in acid soil.

FIG. 42. The up-to-date farmer tests his soil with litmus paper.

The up-to-date farmer is a scientist. He tests his soil, and if he finds it acid he " sweetens " it by applying finely pulverized limestone, marl, or air-slaked lime. In later chapters we shall have occasion to refer again to acids, and we shall study some of the substances that have the power to neutralize* or destroy them.

One of the most important of the acids is hydrochloric acid, a compound of hydrogen and chlorin. The element chlorin and its compounds will be studied in a later chapter.

CHAPTER EIGHT

A STUDY OF WATER

FIG. 43. Water in the winter time.

WHAT is water? This question may seem very easy to answer, because water is so common and so well known. It is very common, but is it well known?

Every one is more or less familiar with ice, water, and steam, and most boys and girls know that these are thought of, not as three different things, but as three different forms of the same thing. They can readily be changed from one of the forms to either of the other two. How?

Exercise 1. Write a description of water as it is found out-of-doors in the northern part of the United States during the winter time. Read up on the subject in an encyclopedia; at least consult an unabridged dictionary.

Exercise 2. Write a second description of water, as it appears in the summer time. Consult a text on chemistry.

Exercise 3. Write a third description of water, as it is found at the mouth of the spout of a teakettle in which the water is boiling vigorously. Put your finger cautiously into what appears to be empty space at the mouth of the spout. With what is that particular space filled? Is water vapor, or **steam**, visible?

After escaping steam is cooled by the air, it condenses into small drops which make a cloud or fog that is visible. This is not true steam, and if you will heat it by holding a flame near it, the droplets of water will again be changed into invisible vapor. Real steam is invisible.

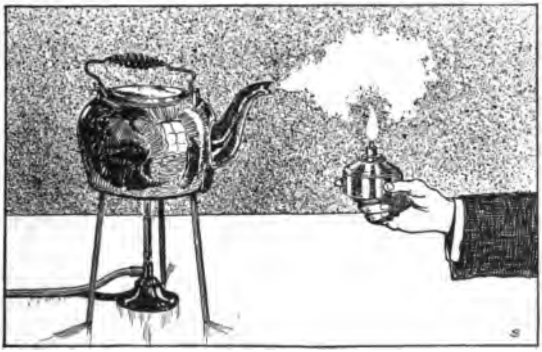


FIG. 44. Real steam is invisible.

Occurrence of water. We may find water in some rather unexpected places. Let us continue to study the subject and ascertain by experience some facts concerning the occurrence of this abundant and interesting substance.

Exercise 4. Put a piece of raw potato in a test tube and heat it gently, keeping the top of the tube cool. What condenses* along the sides of the tube?

Repeat the experiment with a piece of ripe apple. Do the same with a piece of "green" wood. Now try a bit of dry pine shavings. From all these you have derived water.

Many minerals, rocks, and stones contain water, as the following experiment will show:

Exercise 5. Obtain samples of gypsum (calcium sulfate) and blue vitriol (copper sulfate), and gently heat each of them in a test tube. They will both yield water.

The bodies of all animals contain a large amount of water. If a man weighs 150 pounds, at least 90 pounds of that weight is water. Lean meat contains from 50 to 75 per cent of water. If you buy 4 pounds of meat, for how much water do you pay?

Exercise 6. Lean steak contains on an average 8 per cent bone, and 65 per cent of the remainder is water; dried beef contains no bone and is about 45 per cent water. Is it cheaper to buy steak at 25 cents a pound or dried beef at 40 cents a pound?

The facts contained in the following table will give rise to other interesting questions:

Bread contains about	35	per cent of water
Fresh fish (edible portion) contains about	75–80	per cent of water
Flour contains about	12½	per cent of water
Apple (edible portion) contains about	84	per cent of water
Turnip (edible portion) contains about	90	per cent of water
Watermelon (edible portion) contains about	92½	per cent of water
Cucumber (edible portion) contains about	95	per cent of water
A jellyfish contains about	98.9	per cent of water

The water-holding capacity of the air. Water vapor is a part of the atmosphere; some of it is always present in the air. The amount of vapor that the air can hold depends on the temperature. If the temperature is high, the air can hold as much as 4 ounces of water in every cubic yard. At 100 degrees F. it holds somewhat less than 4 ounces; at 80 degrees, about 2 ounces; at 50 degrees, a little over three quarters of an ounce; and at the freezing point of water (32 degrees) it holds slightly more than one third ounce per cubic yard.

When air contains as much water vapor as it can hold, it is said to be saturated. What would happen if air saturated with water vapor at 90 degrees were suddenly cooled down to 60 degrees? What happens every time the air becomes saturated and the temperature falls?

Exercise 6. Compute the weight of water contained in a room that is 21 by 36 feet and 9 feet high, with the air at 100 degrees F. and completely saturated.

Exercise 7. What does your geography say about the proportion of land and water on the surface of the earth?

Rain. Large bodies of water like the Great Lakes and the oceans are the source of the largest part of the water vapor in the air. As the vapor rises from the surface of these bodies of water, it is carried by the winds out over the land. It is next condensed into clouds, and under certain conditions the minute droplets of water which form the clouds unite into larger drops and fall as rain. What becomes of clouds when they disappear without falling as rain? About eight elevenths of the

water that falls as rain flows through the rivers to the sea.

A summer shower. Very few persons stop to think of the great amount of water that falls in an ordinary shower. A very light shower will precipitate perhaps one one-hundredth of an inch of water. Not very much, you say; but how much falls, at that rate, on the surface of a lot 50 by 100 feet? Water weighs 62½ pounds per cubic foot. How many pounds of water will the very light shower throw down upon an acre? How much upon a square mile? Heavy rains may give a depth of one inch per hour or sometimes more. What will be the total weight of water from an hour of such a rain upon a square mile? Upon the county or city in which you live? If a shower precipitates one fourth of an inch, how much would the water upon a square mile weigh?

Rainfall. It is very interesting to know the depth of the annual rainfall for the locality where you live and to know the time of the year when most of the rain falls, as upon these two factors depend the kind and amount of the crops that can be raised. To make a rain gauge by which rainfall can be measured, place somewhere out in the open a rather deep vessel with vertical sides (Fig. 122, page 206). The most accurate results will be reached if the vessel is buried nearly or quite even with the ground.

Snow. When a cloud passes into air that is below the freezing point of water, the droplets of water are changed to small ice crystals. These little crystals

FIG. 45. Some forms of snowflakes.

unite to form a wonderful variety of beautiful six-sided stars which we call snowflakes. Snowflakes grow, as they fall, by condensing additional moisture from the air. They are larger in mild than in cold weather. Over 1000 different forms of snowflakes have been observed. If perfect they are always six-sided. They form best in still air.

Exercise 8. Catch snowflakes, as they fall, on a black cloth or paper and examine their forms. Perhaps you can catch the snowflakes on your coat sleeve on the way to school. A magnifying glass will be helpful in determining the forms of the flakes.

Sleet. Snowflakes lose their regular form when they are driven about by a wind, and if this occurs when the snow is just on the point of melting into water, sleet is formed. When the ground is colder than the air, the sleet freezes and forms a coating of smooth ice upon the ground and the trees. Although this condition leads to many accidents, it furnishes one of the most beautiful visions of the winter time in our northern states.

A snowfall. The amount of water in a snowfall is equal to about one tenth of its depth. Write in your notebook all the good results you can think of that

follow a fall of snow that comes and remains upon the earth for weeks or months. The fall of snow is heaviest in the cool temperate regions. Near the poles there is not enough moisture in the air for heavy snowfalls.

The sea. What per cent of the surface of the earth is covered by water? Name the oceans in the order of their size, beginning with the smallest.

What is the greatest width of the Pacific Ocean in miles? How far is it from San Francisco to Honolulu? From New York to Liverpool? From New York to Buenos Aires? What have you learned concerning the depth of the water of the oceans? Is the land under the sea diversified into mountains, valleys, and plains? How do the depths of the sea compare with the heights of the land areas?

Water a powerful solvent. Water is everywhere acting to dissolve the various materials with which it comes in contact. Scarcely anything escapes its solvent* power. The water which falls from the clouds in rain or snow is quite free from foreign substances; but after falling on the earth and soaking into the ground, it becomes filled with many substances that have been dissolved in it.

Exercise 9. Put a lump of sugar in water. The liquid will enter into the sugar until it has passed into every portion of it. If there is enough water present, the sugar will entirely disappear in the water, forming a solution of sugar in water. If any portion of the solution is tested by the sense of taste, it will be found to be sweet, thus showing how complete the solution is.

Exercise 10. Place some clean, clear water from a well or spring in an evaporating dish and boil it until the water is gone. Usually a whitish residue* will remain. This is the mineral matter that was in the water. Is the inside of the teakettle that is used in your kitchen coated with mineral matter?

Because of its solvent power water often hollows out great caves in the earth, and all our rains carry large amounts of minerals to the sea. What becomes of these minerals when the water is evaporated from the ocean? Where did the salt in the ocean come from?

The solvent power of water increased by heat and carbon dioxid. The solvent power of water is greatly increased by increasing the temperature, and for this reason water that finds its way deep down into the earth, where the temperature is high, will dissolve much more of the solid minerals and rocks than it could dissolve at the surface of the earth. Again, when water has fallen upon the earth and passed through the soil it becomes charged with certain gases, especially carbon dioxid, by means of which it will then dissolve solid limestone (page 148).

Sometimes water that has gone to great depths in the earth may come to the surface again with more mineral matter than it can hold in solution, so that, when it cools and the carbon dioxid in it escapes, the mineral matter is deposited. If this water comes into a cave or cavern, the water drips from the roof and is evaporated, leaving the limestone in the form of stalactites* or stalagmites*. If the water issues as a

FIG. 46. Mineral matter deposited by the waters of a hot spring in Yellowstone National Park.

hot spring, very beautiful mineral deposits may be built about the mouth of the spring.

Organic matter in water. Water from a swamp or stagnant pool is usually brown or black in color. This color is due to the presence of organic or vegetable matter.

Exercise 11. Evaporate to dryness a vessel of water from a swamp or stagnant pool. Note the dark-colored organic matter which remains. Heat the residue very hot, and the organic matter will all be burned out. The gray or white ash which remains is mineral matter.

Disease germs in water. The disease germs that attack us are little plants and animals, — plants and animals so small that they can be seen only through a powerful microscope. Their home is in the human body, where they live surrounded by the fluids of the body. They are adapted to a liquid habitat*, and drying is fatal to them. When they reach the outside world,

therefore, they quickly die in such places as the dust of streets. If germs get into water, however, many of them live for a number of days. This makes water particularly dangerous as a carrier of germs, and care must be taken to exclude germs from drinking water. Like other plants and animals, disease germs are killed by heat, and if water is heated for a few minutes to 150 degrees, any germs of human disease that are in it will die. Bringing water to the boiling point will make it safe for drinking purposes.

Exercise 12. Boil a flask of water for half an hour. Allow it to cool and then drink some of it. Note the "flat" taste. Heat another flask of water, but remove it from the fire as soon as bubbles of steam begin to appear in it. Cool it and note the taste. The flat taste in boiled water is due to the air having been driven out. If water is brought just to the boiling point, its drinking qualities will not be impaired and yet the germs in it will be killed.

Where does a fish get the oxygen that it must have in order to sustain its life? Why does the porpoise* or the whale come to the top of the water to breathe?

A study of the chemical composition of water. There is a very instructive experiment which will interest you, though you may not possess the apparatus for making it yourself (Fig. 47). It will answer an important question which the chemist is always asking, not only about water, but about every substance in which he becomes interested. This question is: Of what is it composed? The ancients called water an element because they

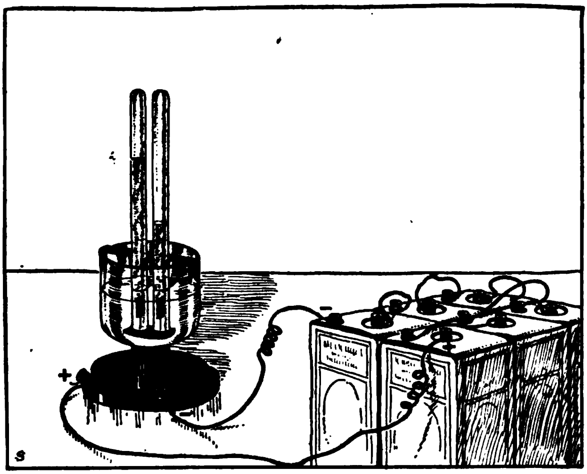


FIG. 47. The liquid water is broken up into two gases, hydrogen and oxygen.

knew no method by which it could be resolved into anything more simple than itself.

Breaking water into two gases. Figure 47 shows an apparatus for decomposing water. It consists of a battery of electric cells, the wires of which end in platinum strips, called electrodes. These electrodes are in the open ends of test tubes which have previously been filled with water to which a small amount of sulfuric acid has been added. The water between the test tubes forms part of the circuit of the battery, and when the current begins to flow, the electricity passes from one electrode to the other through the water. When this happens, the molecules of water are broken up and bubbles of gas are seen rising in the test tubes. It will

be noticed that the gas collects in one of the tubes about twice as fast as in the other.

The gases formed from water. The question of the chemist is not yet answered, and it will not be until he finds out the character and names of the two gases.

If the tests described on page 52 are repeated with the gas which collects in the greatest quantities, it will be found that this gas is hydrogen. The experiment has taught us, therefore, that water is in part composed of hydrogen. We have also observed that of the entire amount of gas obtained from the water, two thirds of it, measured by volume, is hydrogen.

Read the experiments described on page 46 and make the same test on the gas in the second tube. It will be found that this gas is oxygen. Water is in part composed of oxygen.

In Exercise 3 on page 52, hydrogen and the oxygen of the air were made to unite, and the product of their combination was water. Putting that fact with what we have just learned, we conclude that water is a compound formed by the chemical union of the two gases, hydrogen and oxygen. Each molecule of water contains two atoms of hydrogen and one atom of oxygen. The chemical formula is H_2O.

Can you explain why the study of water properly follows the study of oxygen and hydrogen?

CHAPTER NINE

A PINCH OF SALT

FIG. 48. Manufacturing salt in Syracuse, New York. The brine is pumped from deep wells and evaporated by the heat of the sun. The covers shown along the sides are turned down over the tables at night and during rains.

THERE is no substance in common life which is of greater importance, or which will better repay careful study, than common salt. We know its value in our daily food; without it the food would be insipid* and tasteless. Animals not only do not thrive but cannot even live when deprived of salt for any length of time. Its qualities of preservation are well known to us, as they were to the ancients, who used it in sacrifices. Ancient philosophers and poets have spoken or sung its praises, and to the present day the Arabs and Russians use it as the emblem of hospitality. Among some tribes of barbarous men, who are otherwise very treacherous,

the traveler is safe if he has once partaken of their salt. We shall also see that common salt is the starting point and the basis of many important commercial industries.

Occurrence. Salt is one of the most widely distributed substances in all the world. It is found in the soil, in many rocks, in brooks and rivers, and in large amounts in the sea. It is found in inland lakes, like Great Salt Lake, that have no outlet; the waters escape by evaporation, leaving the salt behind. The common salt of commerce is obtained, in the United States, from deposits in New York, Kansas, Utah, Michigan, Louisiana, and numerous other districts. In many places the salt is dissolved in water, forming brines* which are evaporated to obtain the solid salt. When the brine is allowed to evaporate slowly by the help of the sun's heat, it forms large crystals which are sold in the

FIG. 49. Mining rock salt.

market as "solar* salt." Crystals of greater purity can be obtained by using artificial heat and constantly stirring the solution. To purify our coarse salt for table use, the bitter ingredient of magnesium chlorid must be removed.

Exercise 1. Procure samples of refined table salt and also of the common cheap salt that is sold by the barrel. It may also be possible to procure a small piece of rock salt. Ascertain the current market prices for each of these grades, as that will be one way of judging of their relative purity.

Exercise 2. Test the three varieties of salt as to taste. Do you notice a difference? Which contains the most pronounced bitter taste?

Can you describe a taste? Suppose that some one did not possess the sense of taste; could you describe the taste of salt to him so that he would understand it? Taste can be learned only by experience.

Exercise 3. Examine a small portion of the table salt. Is it solid, liquid, or gaseous? What is its color? Is it malleable or brittle?

Exercise 4. Test the solubility* of common salt by placing it in water and noting how readily it dissolves. Already, in Exercise 2, you have made one experiment bearing on this point. What must always happen to any substance before it will have a taste? Why is it that a clean stone, placed on the tongue, gives no taste? Add more salt to the water. Is it readily or not readily soluble in water? Some substances are *insoluble* in water.

This question as to the solubility of substances, whether they are soluble or insoluble, is one of the most important ones with which the chemist has to deal. If

he knows the solubility of the different substances he is handling, he is often able to foretell what the chemical action will be.

Exercise 5. Spread some table salt on a black paper and examine the particles with a magnifying glass. Are they regular in shape?

Exercise 6. Place a small amount of a salt solution in an evaporating dish and evaporate the water. If more convenient, the solution may be placed in a plate or saucer and the water evaporated by setting the vessel in the sun or near a stove. When the water is nearly all gone, examine and describe the crystals* of salt. Well-formed salt crystals are usually perfect cubes* (Fig. 52).

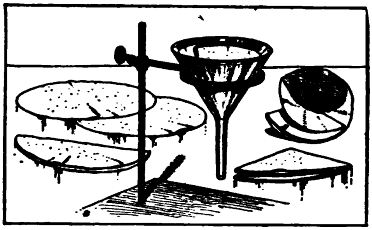


FIG. 50. By filtration the chemist separates insoluble solids from liquids. He also separates in this way soluble and insoluble solids. The illustration shows how a filter paper is folded and placed in the funnel. Explain how you would separate in this way sand and salt.

The physical properties of salt. Now put into a single sentence the facts you have learned concerning salt. You have made a list of the physical properties of this substance; you can define salt from the standpoint of physics. What is salt? Your answer may be that salt is a white, crystalline* solid, very brittle, not malleable, soluble in water, and with a peculiar taste.

A chemical study of salt. When a chemist is working with a substance, he is almost entirely concerned with asking and answering two questions. The first question

is: Of what is it made? The second question is: How will the substance behave, or, what will be formed from it, when it is brought into contact with other substances?

After the chemist has answered these questions, the practical man of affairs — the manufacturer, the physician, the farmer, and others — will ask what the substance is good for. It will thus be seen that the chemist prepares the way for nearly all the activities of agricultural, industrial, and commercial life. Let us now extend our investigation of salt by studying it according to the methods of chemistry.

Exercise 7. Place a small amount of salt in a test tube and add a few drops of sulfuric acid. Is there evidence of a chemical change? Smell the gas which comes from the mixture, but do not inhale too much of it. Notice the sharp, penetrating character of the gas; it is as if the point of a needle had been thrust into the nose. Blow the moisture of your breath across the mouth of the test tube and notice the white cloud which is produced. Hold a moist piece of blue litmus paper in the gas.

You now have several facts to add to your definition of common salt. You can say that common salt is a white, crystalline solid; is soluble in water; has a peculiar taste; is not malleable, but brittle; and also that when treated with sulfuric acid it yields a sharp, penetrating acid gas which is somewhat soluble in the moisture of the breath and is made visible by this moisture.

Hydrochloric acid. The gas produced in the above experiment is hydrochloric acid. It may be recognized by its peculiar odor and the change produced by the

breath. This acid is a gas and when dry possesses no acid properties. It is collected and kept for use by passing it into pure water. What we buy at the drug store, therefore, is a solution of hydrochloric acid in water. It is a most important chemical product that has extensive applications in chemical and other industries.

FIG. 51. The flame test.

The flame test. The flame test is much used by chemists to determine the elements that are present in a substance. Make the flame test on salt in the following manner:

Exercise 8. Dip a platinum or iron wire with a small loop in the end into a solution of salt and then bring it into the edge of the colorless part of a gas or lamp flame. An instantaneous* flash of a brilliant yellow color is seen. Repeat this test until you have become thoroughly acquainted with the peculiar yellow color.

Whenever the chemist sees this yellow color in the flame, he knows that he is dealing with a substance that contains sodium. The ending "ium" indicates that the substance which bears such a name is a metal. Potassium, magnesium, calcium, and barium are metals, and from the ending of its name we may know that sodium also is a metal.

Our definition of salt may now be enlarged to include the fact that it is in part composed of sodium. We may state that it is a white, crystalline, brittle solid, soluble in water, has a peculiar taste, is acted upon by sulfuric acid, giving rise to a strong, penetrating, odorous gas, and also gives the flame test for the metal, sodium.

Composition of salt. We have now found that salt is a compound of sodium. The question which remains to be settled is, what substance is combined with the sodium to produce salt. The method of determining this is somewhat complicated, but any clear-headed person can make some experiments, do a little thinking for himself, and draw conclusions that will be quite satisfactory.

Exercise 9. Take a small pinch of salt and mix with it a like amount of black oxid of manganese (MnO_2). Place in a test tube the mixture you have prepared. Notice that, as far as you can see, there is no action of any kind between the parts of the mixture. Now pour a few drops of sulfuric acid on the mixture and warm it a little by holding the tube near the flame of a lamp but not in the flame. A greenish yellow gas with a strong and disagreeable odor is given off. Do not inhale* any of the gas.

Is the gas that is given off hydrochloric acid? If you cannot readily decide, take some salt in another test tube, put the sulfuric acid on it, and compare the two gases. You will conclude that the gas given off when the manganese oxid is present is not the same as the hydrochloric acid produced when it is not present. The first gas is *chlorin*. Its symbol is Cl.

Where did the chlorin come from? Could it have

come from the manganese oxid? This substance contains the metal manganese and only one other element. What is that element? What does the ending "id" signify to the chemist? The chlorin could not have come from the manganese oxid. It could not have come from the sulfuric acid (H_2SO_4) because that is composed only of hydrogen, sulfur, and oxygen. You conclude that the chlorin must have come from the salt, and your conclusion is correct.

Now, from our entire study of common salt we may conclude that it is a compound produced by the combination of the metal sodium with chlorin. In other words, the white solid which we call salt is formed from a shining, soft metal that burns on water (page 86), and a greenish yellow gas. This fact is expressed by the chemical formula, NaCl. The chemical name of salt is sodium chlorid. It is very fortunate for us who use the salt that, in combining, both sodium and chlorin lose their peculiar properties.

You may again enlarge your definition of common salt so as to include all the physical and chemical properties you have learned. Do this and enter the definition in your notebook. No other substance with which we are acquainted possesses just these properties; and whenever you find a substance having these exact properties, that substance is common salt.

Exercise 10. Repeat Exercise 7, using about a level teaspoonful of salt and an equal amount of sulfuric acid. After the hydrochloric acid has all been given off, pour the contents of the test tube into an evaporating dish and evaporate

FIG. 52. A group of crystals.

to dryness. The white substance remaining in the dish is sodium sulfate, or "salt cake."

The chemical action in this case is as follows:

$$2\ NaCl + H_2SO_4 \rightarrow 2\ HCl + Na_2SO_4$$

salt + sulfuric acid → hydrochloric acid + sodium sulfate, or "salt cake"

By carefully considering this case of chemical action we shall see that the sodium and the hydrogen have exchanged places, and that by this action hydrochloric acid and salt cake are produced. This is a good illustration of what occurs in thousands of other cases when one chemical acts upon another.

Chemistry closely related to industrial life. It is a most interesting fact that the chemist in his laboratory is all the time teaching processes which are used in great industrial plants where millions of dollars are expended and thousands of men are employed. For example, salt cake and hydrochloric acid are produced in great manufacturing plants by adding sulfuric acid to common salt, the exact method we were using in the above experiment. The hydrochloric acid is employed in many chemical and industrial processes, and great quantities of the salt cake are used in making glass and soda. Salt is also used in the manufacture of many

other valuable products: chlorates for explosives; chlorin for bleaching powder; caustic soda, valuable for many purposes; soap; pottery; and a hundred other products, all of which minister to our comfort and our needs. Perhaps some day you will be head chemist in a great manufacturing establishment where some of these products are made.

A study of crystals. In Exercise 6 we discovered one of Mother Nature's most interesting secrets. When the salt was allowed to solidify, crystals were formed which were very uniform as to shape. Of what shape were they?

Crystals of other mineral substances also are very abundant; for it is the almost invariable rule that when any substance in the liquid form is changed to a solid, it takes a crystalline form. If the conditions are favorable, all the crystals formed from a given substance are of exactly the same shape and all have the same number of faces of the same form.

FIG. 53. A crystal of alum.

Exercise 11. Dissolve as much common alum in hot water as the water will hold. Suspend a string in this saturated solution and set it where it will be as quiet as possible. It is best to hang a small weight at the end of the string to help hold it still. After the solution has stood for several hours, there will be crystals of alum upon the string.

Study the form of the crystals. How many and what shaped faces has each? how many edges?

When the crystals cease growing, suspend them in a fresh solution. In this way larger crystals may be obtained.

Exercise 12. Repeat the above experiments, using sugar. Crystals of "rock candy" will be formed. Copper sulfate may be used, but the plan of the crystal is not readily seen.

The different crystals of the same substance will not be of the same size, but they will all be of the same shape. If there is too much material confined in a given space, so that there is not room enough for the formation of perfect crystals, there will still be an attempt to form crystals; but in this case there will be a great number of imperfect crystals joined together in one mass. Such a solid is said to be crystalline. Many of our rocks are solids of this kind.

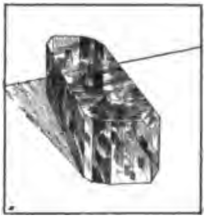


FIG. 54. A crystal of copper sulfate. Perfect crystals of this substance are rarely formed.

It is not an easy thing to find perfect crystals, although almost every locality will afford specimens of some kinds of crystals, and the sharp eyes of an interested observer will find them. Some of the most beautiful crystals are the precious gems. Such are the diamond, the ruby, the emerald, and the sapphire. These and others are very beautiful; and because they are hard to find, they command a great price. All important museums have collections of wonderful crystals of hundreds of different kinds. If possible, visit such a museum sometime and see these beautiful objects.

CHAPTER TEN

CHLORIN AND SODIUM

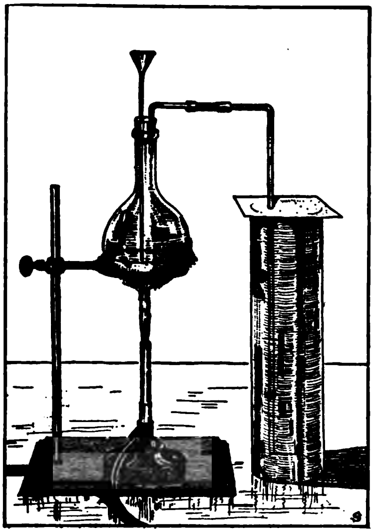


FIG. 55. Preparing and collecting chlorin.

THE study of salt as a compound of sodium and chlorin suggests that it would be of interest to make a further study of the elements, chlorin and sodium, of which the salt is composed. One purpose in making the study is to learn something more of two very common elements. Another purpose is to gain additional knowledge of some chemical processes that are of great importance in our daily life.

Preparation of chlorin. One method of producing chlorin was given on page 78. Chlorin may be obtained from hydrochloric acid also by combining that acid with potassium chlorate.

Exercise 1. Put a small piece (of the size of a kernel of wheat) of potassium chlorate in a glass flask or test tube. Cover it with a few drops of hydrochloric acid and warm gently. The gas, chlorin, will be given off. It may be dissolved by pouring water upon it, or it may be collected in a jar by downward displacement of air, as shown in Figure 55.

FIG. 56. When powdered iron is thrown into a jar of chlorin, a shower of sparks is produced.

Properties of chlorin. At ordinary temperatures chlorin is a greenish yellow gas and has a peculiarly disagreeable odor. At low temperatures and under pressure it becomes a liquid, and tanks of liquid chlorin are bought and sold. It is an active element, combining with many substances, as you can prove by experiment. Do not inhale it, as it produces a feeling of suffocation and causes coughing and intense irritation of the eyes, nose, and throat.[1]

Exercise 2. Throw a small quantity of powdered antimony, or iron powder, into a jar of chlorin. A shower of brilliant sparks is produced as the two elements combine (Fig. 56).

Exercise 3. Moisten a piece of paper with oil of turpentine which has been slightly warmed and drop the paper into a jar or flask containing chlorin. Observe what happens (Fig. 57).

You have already learned that turpentine is a compound of carbon and hydrogen. The chlorin has a strong affinity* for hydrogen and unites with the hydrogen of the turpentine, setting the carbon free. What substance is formed when chlorin and hydrogen combine?

[1] Make it a practice, when you leave the chemical laboratory, to go out into the open air and "wash out" your throat and lungs with deep inhalations of pure air.

An experiment in bleaching cloth will also show the strong tendency of chlorin to unite with hydrogen.

Experiment 4. Moisten a piece of colored cloth and place it in a jar of chlorin. The color will slowly be removed from the cloth.

Repeat the experiment with a colored flower.

In this experiment the chlorin decomposes the water by taking out its hydrogen and setting the oxygen free. The oxygen, at the moment it is set free, has a strong action on the coloring matter of the cloth and destroys it. The color may all be taken out without injuring the cloth, provided the cloth is removed from the gas as soon as the color is gone.

Bleaching powder. Chlorin is manufactured in very large amounts for the making of bleaching powder. In making the bleaching powder, lime is spread in thin layers on the floor of stone chambers and chlorin is passed in. The lime is turned over at intervals until it is thoroughly saturated with the chlorin. When this compound is placed in water, the chlorin is given off and bleaches out the color from cloth which is immersed in it.

Fig. 57. The chlorin unites with the hydrogen of the turpentine, setting the carbon free.

FIG. 58. The sodium combines with the water and releases the hydrogen, which takes fire from the heat of the chemical reaction.

Chlorin as a disinfectant. Chlorin is one of the most powerful disinfectants* known, and both chlorin itself and compounds of it are used to make safe water that may contain disease germs. The chlorin kills germs in the same way that it bleaches cloth, — by decomposing the water and setting free the oxygen, which burns up the germs. Seventeen parts of chlorin in a million parts of water will destroy all germ life; and since the chlorin does not remain in a free form, the taste and drinking qualities of the water are not impaired. By dragging a bag of bleaching powder back and forth through a swimming pool, the water of the pool may be freed from germs. The bleaching powder must be fresh to be effective, and should be applied in the proportion of 2 to 10 ounces to 50,000 gallons of water.

Sodium. Sodium belongs to a class of rare metals, of which sodium and potassium are the best known. They differ from iron, silver, and other metals with which you are more familiar in that they are very soft and light — soft enough to be easily cut with a knife, and so light that they float on the surface of water. The cut surface of sodium shines with the brilliancy of a piece of polished silver. In their pure form these

metals are used only by the chemist, but compounds of them are very abundant and most valuable. Thus sodium chlorid, or common salt, is, as we have learned, found everywhere, in the sea and in the soil, and sometimes in thick beds from which it may be mined. Sodium carbonate, a compound of sodium, carbon, and oxygen, is used in enormous quantities in cooking, glass making, and other industries. Perhaps you are familiar with this compound under the name of "sal soda" or "baking soda."

Strange metals. Sodium and potassium have so strong an attraction for oxygen that they take the oxygen of water away from the hydrogen, thus decomposing the water and releasing the hydrogen as a free gas. The following experiments will illustrate this most remarkable property.

Exercise 5. Into a beaker glass or tumbler one third full of water drop a small piece of potassium. Stand away from it until the very vigorous action ceases. If sodium is used, the water should be slightly warm.

The metals float on the surface of the water; they move about very rapidly and the hydrogen which is given off is set on fire by the heat from the chemical action. The color of the flame is given to it by the metal. If sodium is used, it is tinged with yellow, or with a bright violet color if potassium is used.

Exercise 6. Make a small, deep cavity in a piece of ice and drop into it a small piece of potassium. Immediately a flame appears, tinged with a purple color, as if the ice had been set on fire. A sharp explosion usually ends the

experiment. The flame is produced by the burning of hydrogen which has been pushed out of the water molecules by the potassium (Fig. 59).

FIG. 59. Potassium in a cavity in a block of ice.

Exercise 7. Fill a test tube with water and invert it in a dish of water. Wrap a small piece of sodium loosely in a piece of paper, and with a pair of forceps (not with the fingers) hold it under the inverted test tube. A gas is given off, partly filling the test tube. Carefully lift the tube containing the gas out of the water, keeping the mouth down, and bring its mouth to the flame of a lamp or Bunsen burner. A slight explosion shows the gas to be hydrogen.

Exercise 8. Take a dish partly full of pure, distilled water. Add two small pieces of litmus paper, one blue and the other red. Does the water make any change in the color of either of the papers? Water is said to be neutral* to litmus; it does not change its color.

Exercise 9. Place red litmus paper in water on which sodium or potassium has acted. It turns blue, showing that a new substance has been produced in the water. It is plain that the new substance is not an acid but an alkali.

Cautiously taste the solution. Touch your finger to it. Notice the "soapy feel." Some new compound has been formed by the sodium and the water.

The story of what has happened is as follows:

$$\underset{\text{water}}{H_2O} + \underset{\text{sodium}}{Na} \rightarrow \underset{\text{hydrogen}}{H} + \underset{\text{sodium hydroxid}}{NaOH}$$

The sodium has displaced one of the hydrogen atoms in the molecule of water, making a new substance, sodium hydroxid (NaOH). This new substance is commonly called caustic soda, and it belongs to a class of compounds known as bases.

Bases. In the chapter on hydrogen you studied about acids and tested certain substances for acidity* with litmus paper. Some substances turned the litmus paper red; other substances made the blue color more intense, or, if a red paper were used, turned it blue. These latter substances are known as bases, and they are alkaline* to the litmus paper. The best examples of bases are what are commonly called "potash" and "soda." Other examples are baking soda and lime.

Properties of a base. Three properties which may be used to distinguish a base are:

(1) It is caustic or burning to the taste.

(2) It will turn red litmus paper blue.

(3) It always contains a metal with oxygen and hydrogen.

Compare these properties with the corresponding properties of acids (page 58).

Acids and bases neutralize each other. Another experiment will give an interesting illustration of the behavior of a base.

Exercise 10. In a weak solution of hydrochloric acid place a small piece of litmus paper. What color is produced?

Are you dealing with an acid or a base? Now add slowly a weak solution of caustic soda (sodium hydroxid). Stir the mixture thoroughly and continue to add the acid until the litmus is turned to a very faint blue color. Save the solution for use in the next experiment.

In this experiment the base has destroyed, or neutralized, the acid; or, rather, the acid and the base neutralized each other. After the acid was all used up, the solution became alkaline and the litmus turned blue. Whenever acids and bases are brought together they neutralize, or destroy, each other in this way.

Some practical uses of a chemical principle. The busy bee extracts the sweets from the flowers and for the most part deposits them in his curiously constructed comb as honey. A part of the sugar, however, is changed in the body of the bee to an acid known as formic acid, and when the bee stings us we get the benefit of this acid. To allay the poison of the sting we apply ammonia or baking soda to the wound. These are bases, and their healing power lies in their ability to neutralize the acid of the sting. We neutralize the acid of sour milk by the use of baking soda; the thrifty housewife saves her sugar by dusting soda over a rhubarb, gooseberry, or cherry pie; and the farmer "sweetens" his soil by treating it with lime. In all these cases a base is being used to destroy the sour acid which injures or offends us.

Salts. When an acid and a base neutralize each other, they do not cease to exist. What becomes of them? A continuation of our last experiment will give us light.

Exercise 11. Place the solution from the last experiment in an evaporating dish and heat it to drive off the water. The dry substance which remains is common salt. Taste it to learn that it is salt.

Common salt is only one of a great number of compounds which chemists call salts. Whenever an acid and a base neutralize each other, a salt is formed. There are hundreds of different kinds of salts, and when the chemist uses the word "salt" he does not mean by it the one substance which we commonly know as salt.

What happens when an acid and a base act on each other. What really took place in Exercise 10 was the following:

$$NaOH + HCl \rightarrow NaCl + H_2O$$

sodium hydroxid + hydrochloric acid → sodium chlorid + water

The sodium of the base changed places with the hydrogen of the acid. Study out the full meaning of this statement and see if it is clear to you that in the above chemical reaction common salt and water would be formed. Whenever an acid and a base act on each other, they exchange or trade atoms. The acid gives the base its hydrogen and receives in exchange a metal.

This kind of chemical action is known as neutralization. It takes place whenever a base and an acid are brought together. One product of the process is always water, and the other product is a salt. Salts are much more numerous in nature than acids or bases because of the fact that when an acid is produced there is likely to be some base present which will neutralize it into a salt.

CHAPTER ELEVEN

A STUDY OF A MATCH

SULFUR AND PHOSPHORUS

FIG. 60. One way of carrying fire.

In these days of Welsbach burners and Mazda lamps, it will be interesting to get from Grandmother the story of the tinder box and the flint and steel as a means of obtaining fire; or of how, failing to get the fire in this way, the housekeeper borrowed a pan of live coals from a neighbor's kitchen; or, perhaps, carried the fire home upon a stick which was kept alive and glowing by waving it back and forth in the air. In olden times, fires were not allowed to go out, for the reason that there were no matches to light them again. Let us study in this chapter the convenient little article that now makes it possible for us to have fire and light at any time.

The first matches. Early in the nineteenth century it was discovered that potassium chlorate mixed with sugar would burst into flame when acted upon by sulfuric acid. Following this discovery an inventive genius placed upon the market a box containing one hundred splints of wood previously soaked in a solution of potassium chlorate and

sugar, and a little vial holding asbestos* saturated with sulfuric acid. For the hundred matches and the vial of acid he charged a guinea*, and only the well-to-do could afford them. The result of bringing together the chemicals that were used in these first matches may be seen in the following experiment:

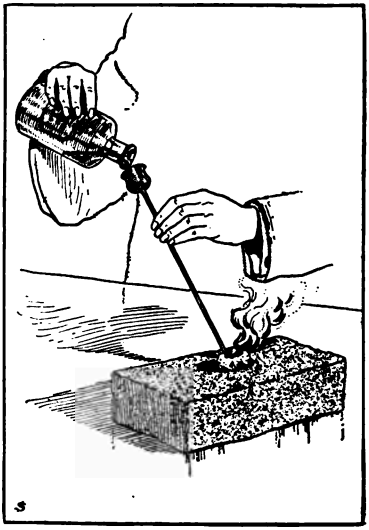


FIG. 61. An experiment to show how fire may be kindled by chemical action.

Exercise 1. In a clean porcelain mortar, pulverize a small amount of potassium chlorate ($KClO_3$) to a fine powder. In doing this, care must be taken to see that the pestle and mortar are perfectly clean and free from organic matter and that the potassium chlorate is free from dust. Avoid violent percussion* or heavy pressure upon the contents of the mortar. Place the powder on a piece of paper and add an equal bulk of granulated sugar ($C_{12}H_{22}O_{11}$) which has previously been dried and powdered. Mix the two materials together carefully, without rubbing them, as the mixture is likely to explode if strongly rubbed. Place the mixture on a brick or stone out of doors or in a strong draft of air. Let fall upon the mixture a drop of sulfuric acid from the end of a glass rod. A very quick chemical action will follow, with a violet-colored

National Match Company

FIG. 62. Unloading basswood logs at a match factory.

flame. The color of the flame is due to the vaporization* of the metal potassium contained in the potassium chlorate.

The friction match. The friction match was invented in 1827 by John Walker, an English chemist. He used a mixture of antimony sulfid (Sb_2S_3) and potassium chlorate ($KClO_3$) on the end of a splinter of wood. This had to be rubbed between two pieces of sandpaper. Afterwards, phosphorus was substituted for the antimony compound and sulfur for the potassium chlorate. These and other chemicals are used to produce the different kinds of matches now found upon the market.

What is needed for the end of a friction match is a substance that will take fire easily, and the chemist can supply a number of combinations of chemicals that will do this. The matchmaker then mixes these chemicals with clay, whiting, starch, gum, rosin, lampblack or a

dye, glue, and other materials, dips the ends of pine or basswood splints into the mixture, and sells the results of his labor in the form of the modern match.

National Match Company

FIG. 63. Scene in a match factory. 600 match sticks are punched by machinery into holes in each of the plates, which form the sections of the great belt shown in the illustration. The belt passes over the dipping kettles, where the tips of the sticks pass through the chemicals, after which the matches are carried over the wheels until dry. They are then punched out of the plates and fed automatically into boxes. One machine will turn out 6,000,000 matches in 10 hours.

Two varieties of the friction match. Two varieties of the friction match are in common use: the strike-anywhere match and the strike-on-box kind. In making the strike-anywhere match, about half an inch of the stick is first soaked in melted paraffin or sulfur. Then the head is coated with some easily combustible chemical mixture to which fine sand or powdered glass has been added to keep the head porous and thus allow the entrance of air. Lead oxid and phosphorus, or potassium chlorate and phosphorus, are the chemicals often employed in making matches of this kind.

The strike-on-box match differs from the strike-anywhere variety in that part of the chemicals are on the match and part on the box. Such matches can be easily ignited only by friction of the match on the box, and are therefore called "safety" matches. But experience with them shows that they are open to some serious objections. Usually the splints are smaller and thinner than the sticks of the ordinary match and the wood is of inferior quality. They break easily and there is danger that a blazing match head may fly into inflammable materials.

Determining the presence of phosphorus and sulfur in matches. You will not be able to determine all the chemicals used in making a match, but by experiment you can learn to recognize the presence of two elements, phosphorus and sulfur, that are very commonly used.

Exercise 2. Strike different kinds of matches, and observe them closely as they burn. Some of them will give off a little cloud of smoke immediately after the match is lighted. In some cases a bluish flame will be seen, or, if the match is held close to the nose, a stifling odor will be detected.

To a chemist, the appearance of the white cloud means that the match contains the element phosphorus. The cloud is composed of fine particles of a white solid which is produced by the union of the phosphorus of the match with the oxygen of the air. It is an oxid of phosphorus (P_2O_5).

The blue flame which follows the white cloud suggests sulfur to the chemist. He smells the stifling gas and at

once recognizes the odor of sulfur dioxid (SO_2), a substance which is formed when sulfur unites with oxygen.

Occurrence of phosphorus. Compounds of phosphorus are found in the yolk of egg and in considerable amounts in nuts, peas, wheat, and other vegetable products. Calcium phosphate ($Ca_3[PO_4]_2$) forms about 25 per cent of the bones of animals, and the same compound is scattered in soils. Occasionally it is found in great deposits as a mineral called rock phosphate. Very valuable phosphate deposits are found in South Carolina and Tennessee.

Uses of phosphorus. This element is necessary to the growth of vegetable products, and these, in turn, when used as food by man and other animals, supply the needed phosphorus to the bones and muscles, nerves and brain. Hence it is that rocks containing phosphorus are necessary and valuable ingredients in fertilizers* used to enrich the soil. The most extensive known deposits of phosphate rocks are in our own country. These rocks are mined and shipped for fertilizers to the different countries of Europe.

Manufacture of phosphorus. Phosphorus is manufactured from natural calcium phosphate by mixing it with sand (SiO_2) and coke and heating the mixture in an electric furnace. The phosphorus separates as a vapor and is condensed to a solid under water. White phosphorus will ignite and burn furiously if left exposed to the air and for this reason is kept under water. It should never be touched with the hands, as it may stick to the fingers and cause very severe burns. It is very

poisonous, and phosphorus matches should not be left where young children can reach them.

Occurrence of sulfur. Formerly sulfur was obtained from the deposits to be found in volcanic regions. Under the action of the heat of the volcano the sulfur was separated from its compounds and brought to the surface. By melting the sulfur away from the impurities a comparatively pure product was obtained. Sulfur produced in this way was shipped from Sicily and Iceland to all parts of the world. More recently enormous deposits of nearly pure sulfur have been discovered in Louisiana; and although the material is solid and covered with 900 feet of quicksand, clay, and rock, it is lifted to the surface. The ingenious method by which this is done is one of the engineering triumphs of our age.[1]

Uses of sulfur. Sulfuric acid (H_2SO_4), the most important single chemical that could be named, is made from sulfur. Sulfur dioxid, which is produced by burning sulfur, is used in bleaching feathers, straw, and wool and in paper making. Pure sulfur is used in making gunpowder, matches, and fireworks, and in the vulcanizing* of rubber. Farmers and the owners of orchards and vineyards make much use of sulfur compounds

[1] Borings are made and in each boring 4 pipes are extended downward to the sulfur bed. The pipes have diameters of 8 inches, 6 inches, 3 inches, and 1 inch respectively, and the smaller pipes are placed inside the larger. Water heated to 170 degrees Fahrenheit is pumped down the 2 larger pipes, which melts the sulfur. Compressed air is then forced down the 1-inch pipe and this causes the liquid sulfur to rise through the 3-inch pipe.

as a spray to destroy the parasites* that otherwise would blast the apples and other fruits.

The meaning of "ate" in chemical names. In this chapter we have used a number of chemical names that end in "ate," — potassium chlorate, potassium nitrate, and calcium phosphate. When the name of a chemical compound ends in "ate," the substance contains oxygen in addition to the elements mentioned in the name. Thus, potassium chlorate contains potassium, chlorin, and oxygen; calcium phosphate is made up of calcium, phosphorus, and oxygen; silver nitrate contains silver, nitrogen, and oxygen; calcium carbonate, or limestone, contains calcium, carbon, and oxygen.

Matches and fires. Most fires are caused by the careless throwing away of lighted matches. An experiment will show how the match manufacturer is lessening the danger of fire from this source.

Exercise 3. Ignite splinters of dry pine or basswood. Blow them out and note if the wood continues to glow after the flame has been extinguished.

In the same way test matches of several different kinds. Does the wood of some of them cease to burn as soon as the flame is blown out?

The wood of matches is now often "fireproofed" by impregnating* it with certain chemicals. Sodium phosphate or alum may be used for this purpose.

CHAPTER TWELVE

CARBON AND ITS COMPOUNDS

In a former chapter we learned that oxygen is the most abundant element in the crust of the earth and therefore the greatest in amount in the soil. If we turn our attention to the things that live and grow in this soil, we shall find that in them by far the most abundant element is carbon.

Carbon is extremely important, because it is the principal element in all organic* substances; that is, in all things which have been produced through the agency of life. This will include all forms of animal and vegetable life, all animals and plants. Chemically considered, a blade of grass, a rose, a potato, an ox, and a man differ but little; all of them contain a large percentage of carbon combined with hydrogen, oxygen, and nitrogen, with small amounts of phosphorus, sulfur, and a few other elements. Carbon is the chief element in our foods, in wood, coal, straw, feathers, hair, leather, — in everything, in fact, that is formed by animals and plants. Every molecule of all these compounds has one or more atoms of carbon as its center, and it is this remarkable element that we are about to study.

FIG. 64. A hod of carbon.

Carbon is also to be found in the vast beds of lime-

stone occurring in all parts of the world, and in the air it exists in the form of the gas, carbon dioxid.

Exercise 1. Fill an ignition tube, provided with a delivery tube of glass, with shavings or small pieces of soft wood, and heat it in the flame of a lamp or Bunsen burner. A mixture of a number of gases composed of carbon, hydrogen, and oxygen will be given off. Light the gas at the end of the delivery tube.

After the flow of the gas has ceased, put a solid cork in the open end of the test tube so that no air can enter, and let the apparatus stand until it is cold.

The contents of the tube will be found to be that form of carbon known as charcoal. The gas given off is an impure illuminating gas, which burns rather intermittently* if lighted at the end of the pointed, drawn-out end of the glass delivery tube.

Exercise 2. Examine the charcoal and make a list of its properties. Is it solid, liquid, or gaseous? It is an interesting fact that you probably never will see pure, elemental carbon in the liquid or gaseous condition. Is it soluble in water? Has it a taste? Has it an odor? Heat a portion of it and observe that it glows but does not burn with a flame.

Charcoal burns slowly and without smoke; hence it is used for many purposes where continued heat is required. The plumber or tinner will carry his charcoal fire to the top of a building where he is at work.

The manufacture of charcoal. Charcoal is made on a large scale by piling logs of wood in a large mound or heap around a central aperture,* which serves as a

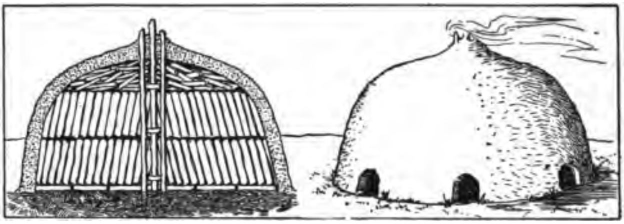


FIG. 65. A charcoal kiln.

chimney. The heap is covered with sods and earth, or a kiln* of brick is built around it; but in either case a number of openings are left for the admission of air. A fire is built at the center and the whole mass slowly burned for several days. The chemical action here is exactly the same as that which took place in the ignition tube: the hydrogen and oxygen of the wood, combined with a certain amount of carbon, are driven off as gases. The remaining carbon is left behind as charcoal. This forms about 65 or 70 per cent of the bulk of the wood and four tenths of its weight.

Exercise 3. Put into an ignition tube enough soft coal to fill one third of the tube. Heat the coal and collect in bottles the gas which comes off. Light the gas at the end of the delivery tube. It will burn with a yellow flame. This also is an impure illuminating gas.

Coke. As soon as gas ceases to be given off and the tube has cooled, break the tube and examine the black solid which it contains. This solid is coke, a form of carbon which is practically the same as charcoal, but usually more solid and compact. Coke making is a great industry, and large quantities of illuminating gas

are secured from the coal that is heated in this process. Procure samples of coke from a coal yard and examine them thoroughly. Charcoal and coke are used very extensively as agents for the reduction of the ores of iron, copper, lead, tin, and other metals. What that statement means can be understood by a single illustration.

Iron ore is iron oxid, a compound of iron and oxygen. When this ore is mixed with coke or charcoal and heated to a high temperature, the carbon unites very vigorously with the oxygen of the ore and leaves the metal in the free state.

In other words, the coke takes the oxygen away from the iron, leaving the iron atoms behind to combine with each other and form molecules of iron. This process of taking oxygen away from a substance is called by the chemist reduction. It is the opposite of oxidation. What is oxidation?

$$\underset{\text{iron ore}}{Fe_2O_3} + \underset{\text{coke}}{3\,C} \rightarrow \underset{\text{iron}}{2\,Fe} + \underset{\text{carbon monoxid*}}{3\,CO}$$

Lampblack, or soot. This is finely divided charcoal. In performing the experiments described on pages 55 and 84 you have already produced it, and small amounts of it can be secured in a still simpler way.

Exercise 4. Press down an iron spoon or porcelain plate upon the flame of an oil lamp or candle. Carbon is deposited on the spoon or plate. Where does it come from?

The explanation of this experiment is that the temperature of the flame is lowered below the burning point of the carbon.

FIG. 66. Collecting lampblack.

How lampblack is manufactured. Lampblack is manufactured commercially from tar, crude petroleum, resin, or pine knots that are rich in resin and turpentine. The process is as follows: The carbon-containing substance is heated in a vessel, and the vapors from it are driven into a chamber in which there is a scant supply of air. A dense cloud of unburned carbon particles enters the chamber and collects on canvas hung on the walls of the chamber. This deposit is scraped from the walls at suitable intervals by lowering a hood.

The lampblack so produced contains many impurities, such as oils and tars. It is separated from these by heating to redness. The principal use of lampblack is in the manufacture of printing inks. It is also used for the production of India ink and for a cheap black paint.

Graphite. Graphite* is a second form of carbon. It is found in certain parts of the world in the form of a mineral. It is always opaque,* of a black or lead-gray color, and of a metallic luster.* The most familiar use of graphite is in the so-called "lead" pencils. The

finely ground graphite is mixed with clay to give the required hardness and is then molded in the form seen in the pencil. It is also used in common stove polishes, in the manufacture of crucibles* for use in the chemical laboratory, and as a lubricant for the chains of bicycles, the cylinders of gasoline engines, and the bearings of other machines.

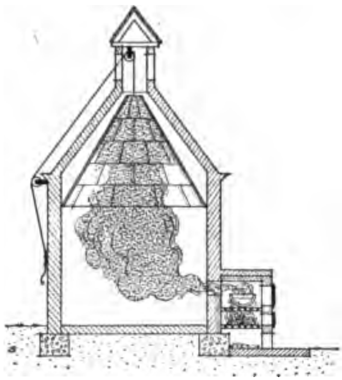


FIG. 67. Manufacturing lampblack.

The diamond. A third form of carbon is the diamond. Stories of some of the noted diamonds of the world may be found in the encyclopedia* or other books of reference. The imagination* must be used to picture to the mind their wonderful brilliancy. The diamond is usually considered the most precious of gems, but the ruby, the emerald, and the sapphire are close rivals in beauty and value.[1] The diamond is noted for its wonderful power to refract the light, sending it forth to dazzle the

[1] It will be interesting to note the comparatively simple chemical composition of some of the precious stones and gems of jewelry.

The **diamond** is pure carbon, C.

The **ruby** is the oxid of aluminium, Al_2O_3, made red by a small trace of chromium.

The **sapphire** also is an oxid of aluminium, Al_2O_2, made blue by a small trace of iron or titanium.

The **emerald** is a complex compound of glucinum, aluminium, silicon, chromium, and oxygen,— $Gl_3Al_2(SiO_3)_6$ + a trace of $CrSiO_3$.

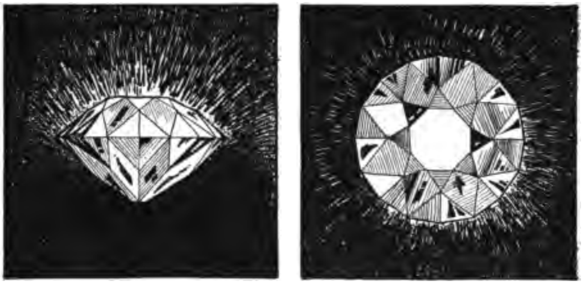


FIG. 68. Crystals of carbon.

eye with its beauty. Diamonds are found chiefly in South Africa and Brazil. When first found they are incrusted over with the rock in which they have crystallized, and it takes the practiced eye of an expert miner to detect them. They are perfect crystals when found, but usually they are put into the hands of a diamond cutter, who grinds new and additional faces to increase their brilliancy.

Composition of the diamond. As chemists, what we are most interested in knowing about the diamond is its composition. When ordinary charcoal is burned in pure oxygen, carbon dioxid is produced; and when the diamond is burned in pure oxygen, carbon dioxid is again produced. In both cases the chemical reaction is:

$$C + O_2 \rightarrow CO_2$$

We cannot, therefore, escape the conclusion that the diamond has the same chemical composition as ordinary charcoal. The difference between them is simply a matter of crystallization. Diamonds have

been produced in the laboratory by subjecting pure carbon to intense heat under high pressure. But the process is very expensive, and only small diamonds have been made in this way.

Carbon dioxid. The fact has already been stated that when carbon is burned in the air, a gas is given off. This is the gas known as carbon dioxid. Notice how appropriate the name is, since the gas is formed from carbon and oxygen and, as is shown by the prefix* di, contains two parts of oxygen to one of carbon. The chemist writes the formula for this gas CO_2.

Occurrence of carbon dioxid. Carbon dioxid is formed whenever any organic substance is acted upon by the oxygen of the air. Thus, if a piece of wood falls to the ground and decays, carbon dioxid is formed. If a similar piece of wood is burned in the stove, carbon dioxid is produced and goes up the chimney. It can be found in the gases which escape from a burning candle, lamp, or gas jet; and in the same way it may be found in the breath which is thrown off from the lungs.

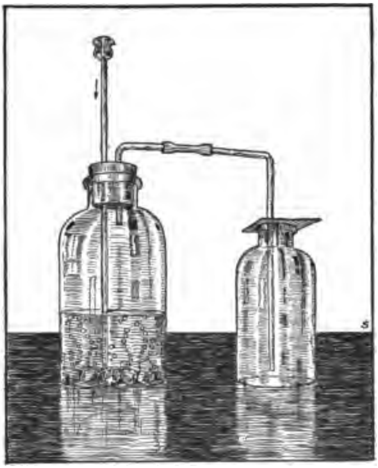


FIG. 69. Collecting carbon dioxid.

FIG. 70. The candle flame goes out when carbon dioxid is poured over it.

In order to become better acquainted with this gas, we shall manufacture it and learn some of its properties.

Exercise 5. Put into a bottle, arranged as shown in Figure 69, small pieces of marble or limestone. Pour dilute hydrochloric acid into the bottle through the thistle tube. Carbon dioxid is evolved at once and may be collected over water or by downward displacement of air (Fig. 69).

Exercise 6. Upon a candle burning at the bottom of a glass (Fig. 70) pour the carbon dioxid collected in Exercise 5 and note the result. The same result may be produced by lowering the lighted taper into a jar which is filled with the gas.

How to test for carbon dioxid. The test which is commonly used in the laboratory for the detection of carbon dioxid is the "limewater test." A saturated solution of fresh quicklime is prepared by pulverizing the lime and placing it in a flask of pure water. The flask is shaken frequently and allowed to stand until the water has dissolved the greatest possible amount of the lime. Then the excess lime is allowed to settle and the clear liquid is drawn off and put into a stoppered bottle for future use.

Exercise 7. Hold a flask or test tube containing a small amount of limewater under the delivery tube of a carbon

dioxid generator (Fig. 69) in such a way that the gas escapes into the water. A white cloud, or turbidity,* appears in the limewater.

As will be explained in a later chapter, this white turbidity or precipitate, as it is properly called, has the exact chemical composition of limestone. Its appearance in limewater is proof of the presence of carbon dioxid.

Limewater + carbon dioxid → limestone

Exercise 8. Expose to the air a small amount of limewater in a saucer or watch glass. Examine the surface of the limewater. Is there carbon dioxid in the air?

Exercise 9. Blow air into a vessel of limewater through a tube or straw. What is the result? What caused it? Where does the carbon dioxid in the breath come from? Give two reasons why you breathe.

Exercise 10. Make a loop in the end of a piece of wire by bending it around a small lead pencil. Pass the wire through a piece of cardboard or stiff paper as shown in Figure 71. Insert the loop of the wire into clear limewater; when it is taken out it will hold a thin film of the water. Lower the wire into a lamp chimney and let the paper cover the top of the chimney loosely. Then set the chimney over a burning

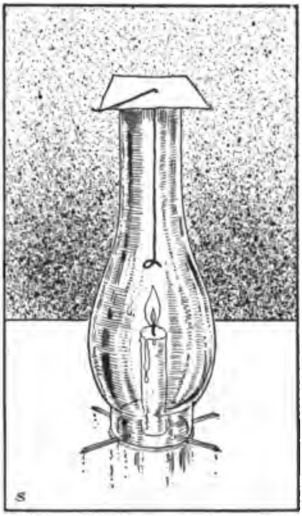


FIG. 71. Testing the air in the lamp chimney for carbon dioxid.

candle. The candle will presently go out, after which the wire may be withdrawn. Notice the cloudy appearance of the film of water on the wire. What was produced by the burning candle?

Exercise 11. Flush out the chimney by washing it in pure air. Clean the wire and dip it again into the limewater. Now hang it in the clean chimney without the candle and allow it to hang for as long a time as when the candle was used. Does the limewater become cloudy now?

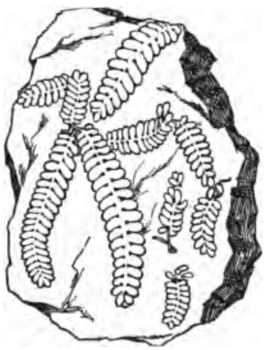


FIG. 72. Prints of fern leaves in coal.

Where does the carbon dioxid that was detected in Exercise 10 come from? Why did the candle go out? What becomes of the carbon dioxid that is constantly being given off into the air? Perhaps you will not be able to answer this last question until you have studied a later chapter in this book.

The origin of coal. Let the pupils obtain samples of "soft," or bituminous, coal, and of "hard," or anthracite, coal. What is coal and where did it come from? Sometimes the prints of leaves can be found in coal, and in coal beds stumps and entire trunks of trees that have been turned into coal have been found. Because of facts like these scientists believe that our coal has been formed from great masses of vegetation that millions of years ago collected in swamps and became buried in the earth. Under the influence of heat, moisture, and pressure a process of slow distillation,* much like

FIG. 73. A forest of the coal period.

that produced by heating wood in an ignition tube, was carried on. In this way much of the material in the plants was driven off, leaving carbon as the chief element in the coal. Where the coal was subjected to great heat, anthracite coal was produced.

A review of what you have learned of carbon. Sit before a coal fire and review what you have learned of carbon. Consider where this element is found, its different forms and compounds, its usefulness to man, and other facts about it that you have learned. The carbon atoms of the coal, which have for millions of years been imprisoned in the earth, are going forth to a new life in the air. Allow your imagination to dwell upon their history and upon what the future holds in store for them.

CHAPTER THIRTEEN

A CAKE OF SOAP

You are asked to make a study of this subject for two purposes, — first to learn some interesting facts about an article of everyday use, and secondly to find in certain common experiences of daily life some further illustrations of the principles and methods of chemistry.

Some one has said that the state of civilization at which a nation has arrived may be measured by the amount of soap consumed. In England there are manufactured over 50 pounds per year for each man, woman, and child. In America the rate is very nearly as high. Before any conclusion is reached by putting these statements together, it should be noted that England sends a large amount of her soap to America, and that Germany, France, and Holland do the same.

History of soap and soap making. We do not know when soap was first used, but it must have been at a very early day. Consult Jeremiah ii, 22, and Malachi iii, 2.

In the collections at the Louvre, the old royal palace in Paris, is a vase supposed to be at least 2500 years old. It bears upon its sides a picture of a group of children blowing soap bubbles from a pipe.

Pliny, the Roman historian, wrote: "Prodest et sapo; Galliarum hoc inventum rutilandis capillis. Fit ex sebo et cinere. Optimus fagino et caprino; duobus modis, spissus ac liquidus; uterque apud Germanos majore in usu viris quam feminis."[1]

[1] "Soap is in common use; it was discovered by the Gauls while dyeing their hair. It is made of tallow and ashes. The best is made of beech ashes and the fat of the goat. There are two kinds, the thick

FIG. 74.

The above is probably the earliest known record of the process of soap making, and it is interesting to note that the method has not changed to any great extent from that day to this. Pliny, the elder, perished at the time of the destruction of Pompeii,* and in the excavations made at that place has been found a complete soap-making establishment, together with some soap in a perfect state of preservation. In essential features, the method of soap making used at the present time does not differ from that used by the Pompeians.

Soap making at an early day in America. Forty years ago the old-fashioned process of soap making was a familiar sight, especially at the farmer's home. At some place near the kitchen door stood a barrel into which were thrown all forms of fat. This constituted the "soap grease," which was allowed to accumulate until spring came and the soap was made. Then some day, when it was convenient, the "leach tub" was arranged. This was a barrel placed upon blocks or upon a platform tilted at a slight angle. Through the bottom of the

and the liquid. Among the Germans each kind is in more common use among men than among women."

barrel several holes were bored. In the bottom was first placed some straw to make room for the lye to flow out, then a layer of lime, and then wood ashes to fill the remainder of the barrel. The ashes were then covered with water, preferably soft warm water. In passing through the ashes the water dissolved certain portions of them, and when the solution came into contact with the lime it changed chemically into what was known as "lye."

Exercise 1. Make a small leach tub in any way convenient. A small box or, better, a large glass funnel and filter paper may be used. Use no lime. You may accomplish the same result by adding hot water to wood ashes in a dish and in this way dissolving from the ashes whatever is soluble. Test this solution with red litmus paper.

Now "boil down" the lye; the chemist would say "concentrate it," or "evaporate nearly to dryness." When this has been done, apply a few drops of acid and notice the very sudden effervescence.* Pass the gas thus produced into limewater by the method described on page 109 and convince yourself that it is carbon dioxid.

You have now discovered two things concerning the lye: (1) it is strongly alkaline, as shown by the litmus paper; and (2) it contains carbon dioxid, from which fact we may conclude that the ashes contain a carbonate. Putting the two facts together, we may conclude that the ashes contain an alkaline carbonate. This may not mean much to the beginner in chemistry, but the trained chemist will know at once, from the above evidence, that the ashes contain either potassium or sodium carbonate. Which of these two it is he may determine by experiment.

Exercise 2. Make the flame test for potassium as directed in Exercise 8, page 77.

The flame test may often be used for the detection of other metals. If the laboratory of the school can furnish small amounts of the salts of the metals that are mentioned in the next exercise, these tests may well be learned by actual experiment.

The general method of making these tests is as follows: A wire is dipped into the powdered solid or concentrated solution of the substance to be tested, and held in the flame. Each metal will give a different color to the flame. The wire must be thoroughly cleaned before and after every test by dipping it in the acid and holding it in the flame until all foreign matter is removed from the wire.

The metal sodium gives an instant flash of bright yellow. This color is absorbed* when a blue (cobalt) glass is held between the flame and the eye of the observer. The glass should be held at arm's length from the eye and not too close to the flame.

The metal potassium gives from its compounds violet or reddish violet color. This is not absorbed* by the blue glass. It is made invisible by sodium if that metal is present.

Exercise 3. (1) Test a pure solution of common salt with and without the blue glass.

(2) Repeat the experiment, using some compound of potassium, preferably the chlorid.

(3) Now test a mixture of salts of the two metals, with and without the blue glass. Can you see with the unaided

eye the lilac color produced by the potassium? Can you see it when the blue glass is used?

Compounds of strontium color the flame crimson. Such compounds are much used in fireworks.

A red color may be obtained from compounds of calcium or of lithium. Make the tests and compare the flames. Which is the brighter?

Compounds of zinc impart a bluish white color to the flame.

A green color may be given by hydrochloric acid, compounds of boron, salts of barium, or copper (except the chlorid).

A blue color indicates copper chlorid, or compounds of lead, arsenic, or antimony.

Potassium in solution from ashes. A delicate lilac color will be produced from the solution of the ashes, and we therefore conclude that wood ashes contain a compound known as potassium carbonate, or carbonate of potash. Its chemical formula is K_2CO_3.

The old-fashioned leach tub, however, contained lime in the bottom, and we must now inquire about the effect which this produced upon the potassium carbonate dissolved out of the ashes.

Exercise 4. Add a considerable quantity of quicklime to the solution obtained from the ashes. Stir it thoroughly and, when it is settled, pour off the clear liquid. This is lye. Save the solid for future testing.

Concentrate the lye by boiling, and test with the acid, the wire, and the litmus paper. It is strongly alkaline; it gives the flame test for potassium; but it does not effervesce

with the acid and therefore is not a carbonate, — that is, it does not contain carbon dioxid.

Exercise 5. Test with acid some of the lime that was used in making the lye. It effervesces with the acid and therefore contains carbon dioxid.

It appears, then, that there has been a chemical action between the lime and the substance obtained from the ashes; the carbon dioxid has left the potassium and united with the lime. By this process lye and carbonate of lime have been produced. What has happened may be told in the following way:

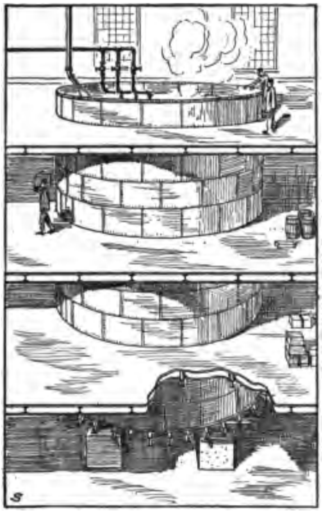
Potassium carbonate + lime → lye + carbonate of lime

Putting together the results we have obtained in Exercises 3 and 4, we may write the following story of all that happened in the leach tub:

Wood ashes + water + lime → lye + carbonate of lime

When the lime is used in the leach tub, the carbonate of lime, being insoluble in the water, remains in the leach tub, while the lye, which is soluble in water, runs through. Lye from wood ashes is known chemically as potassium hydroxid (KOH), or potash. It is manufactured in large quantities for commercial and chemical purposes and is found in every chemical laboratory.

Making the soap. Following the making of the lye comes the day when the soap is to be made. A large iron kettle is procured; the fat is put into it with the lye in about the proportion of 100 pounds of fat to 25 pounds of weak lye, and the two are boiled together. After several hours the fat and the lye have acted upon each



Larkin Soap Company

FIG. 75. A great vat in a soap factory. It extends from the basement through 3 floors of the factory; holds 750 tons; and has in it $1\frac{1}{4}$ miles of steam pipe for heating the soap materials.

other chemically and soft soap is produced. If this is taken into the hand, it may "take hold" strongly, not only cleansing the hand of dirt, but also acting upon the skin itself. In this case, there has been too much lye and not enough fat. If, on the contrary, the product feels slippery and greasy, it is likely that there was not lye enough. It is difficult to adapt* the fat and lye to each other in exactly the right proportions by merely guessing. So, in factories where soap is made in great vats, the chemist is asked to determine exactly how much lye and fat shall be used.

Glycerin. When properly made, soft soap is very pleasant to the sense of touch. This is because it contains glycerin. The exact story of soap making may be told as follows:

$$\text{Fat} + \text{lye} \rightarrow \text{soap} + \text{glycerin}$$

The soap and the glycerin are mixed together; and it is impossible to separate the glycerin from soft soap. But when hard soap is manufactured the separation can be made.

Hard soap. The difference between soft soap and hard soap is due to the materials contained in them. The lye in wood ashes contains potassium, and potassium soaps are soft. To make a hard soap a soda lye (caustic soda, or NaOH) is used. This is purchased by the farmer's wife as "concentrated lye," and the chemist keeps it in a purified form on his shelf.

In making hard soap the soda lye and fat are first boiled together, and when the contents of the kettle have become thoroughly united, a strong solution of common salt is added and the mixture is heated again. Then the boiling is stopped and the kettle is left standing for several hours. The contents of the kettle separate into two portions, the upper consisting of soap and the lower containing the excess of salt, glycerin, and all impurities. The soap thus produced is hard soap.

The glycerin is separated from the water and is used in medicine. When glycerin is treated with nitric acid it becomes nitroglycerin, used in making dynamite* and other explosives.

Free alkali in soap. In the making of soaps on a large scale, great care is taken to use the lye and the fat in exactly the right proportions, to avoid an excess of either fat or lye. If too much lye is used, a part of it remains in the soap as a free alkali, which is very irritating to sensitive skins. Ordinary soap is not suitable for toilet purposes because usually it contains an excess of lye. The presence of free alkali in a soap may be detected by dissolving some of the soap in water and testing it with red litmus paper.

Toilet soaps. In preparing some of the high-grade toilet soaps the raw materials used are of a finer quality. For example, in the making of Castile soap olive oil is used instead of animal fat, and in the manufacture of many soaps perfumes and coloring matters are mixed with the other materials. The mixture is then molded into bars, cut into proper lengths, and stamped into cakes. A high polish is given the cakes by rubbing them with a cloth dipped in alcohol. By beating bubbles of air into soap while it is still in liquid form it is made light enough to float on the water. Glycerin soaps are made by melting hard soap and adding an equal amount of glycerin.

What happens when we wash our hands. Soap is used in removing grease or dirt from either clothes or the skin. We shall try to understand what happens when we wash our hands with soap.

Exercise 6. With any toilet soap make a lather on your hands. Then hold the hands under a faucet or wash them in a vessel of water. Notice how the lather slips off the hands, carrying the dirt and grease with it.

Exercise 7. Put some kerosene or other form of oil into a test tube partly filled with water. Shake the mixture vigorously and notice that the oil or fat has been broken up into small droplets. Let it stand a short time; you will notice that the oil has run together and that it has risen to the top of the water.

Exercise 8. Repeat Exercise 7, but use the white of an egg in place of the water. Notice that the oil is broken as before into droplets and that the droplets remain in that condition, each one being surrounded by, or incased in,

a portion of the albumen* of the egg. This forms what is called an emulsion. The oil or fat is said to be emulsified.

Exercise 8. Repeat Exercise 9, but use a dilute solution of soap with the oil. Shake it thoroughly and let it stand. Does the action of the soap solution resemble the action of the water or the action of the white of the egg? Study the matter until you are convinced that the soap forms a true emulsion with the fat.

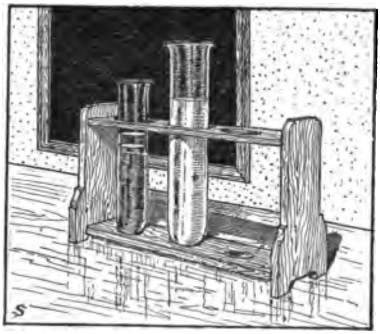


FIG. 76. Water and oil will not mix, but if white of egg be shaken with oil, the oil is broken into small droplets that remain separate.

Do you now understand that soap removes grease or oil from your hands by breaking it up into tiny droplets that are washed away by the water? If you wished to wash your hands in the most efficient and economical manner, would you put the cake of soap into the basin of water or wet the hands and rub the soap on them? Think over this question until you reach a conclusion. Then verify your conclusion by the method of experiment.

Hard waters. Waters that have drained through the earth often have dissolved in them certain chemical salts, especially calcium carbonate, which make them "hard." The "soap test" is a simple method of determining whether a water is hard or soft.

Exercise 10. Take a basin of rain water and a basin of well water. With a small amount of toilet soap, wash the hands in each basin. Notice (1) that the rain water forms a lather at once, (2) that a white precipitate* resembling curds appears in the well water, and (3) that it takes longer to make a lather in the well water than in the rain water. Notice the feel of the precipitate in the well water. Why is water of this kind called hard?

When soap is used with hard water it first forms a chemical compound with the salts in the water. This compound is "thrown down," or precipitated, in the form of the white substance which we see and feel in the water. By this first process the "hardness" of the water is removed, and it is only after this has been done and the water has been made soft that the cleansing process proper can begin.

Material used in the manufacture of soaps. Soaps are often adulterated* by the addition of some cheap bulky materials, for the purpose of giving them a false weight or appearance. Rosin* is added to laundry soap to give it a yellow color and also to make it lather freely. For the same reason shaving soap contains rosin and some proportion of potassium soap to make it soft. Some soaps contain a high percentage of water. Some toilet soaps contain an ingredient which is supposed to have a medicinal value. Scouring soaps are made by adding finely ground sand or pumice stone. Great quantities of coconut oil are used in soap making, and much cottonseed oil is used for the same purpose.

A concluding exercise. As a conclusion to this chapter, you may make for yourself a sample of soap to be kept as a souvenir of your study of one of the common articles of everyday life.

Exercise 11. Melt 1½ ounces of olive or cottonseed oil with 1 ounce of good tallow in a large evaporating dish or tin basin. Then add a solution of not more than an ounce of sodium hydroxid ($NaOH$) dissolved in 2 ounces of water.

Heat the substance gradually until chemical action, or what is known as saponification, takes place. Remove the heat if the contents of the dish tend to boil over. When the action ceases, apply heat again and boil gently for 15 minutes. Now add ½ ounce of common salt, and boil for ½ hour. The hard soap will rise to the top and may be removed. Place the soap in a shallow tin or pasteboard box to mold and allow it to cool. Test the soap for its power to form a good lather.

CHAPTER FOURTEEN

A LOAF OF BREAD

BREAD is the sign of plenty and the symbol of comfort. The cry of a starving person or nation is for bread; the description of hard times in a large city will always include the bread line. Bread is the most important of all the foods that must be provided for an army, and in war time the bake oven follows the army as faithfully and persistently as the soldier follows the flag. Very properly has bread been called the "staff of life." All races of men, even the most barbarous, have learned how to grind various kinds of cereals* — wheat, corn, barley, and rye — into flour or meal for making this staple article of food.

FIG. 77.

The value of bread as a food is shown by the way one explorer subsisted for weeks chiefly upon the various kinds of bread which his Indian guide made from flour. When the Indian merely mixed the flour with water, added a little salt and boiled the dough in water, he had what he called a "slippery-go-down"; when he boiled the dough in the fat extracted from the animals he had captured, he had what he called a "dough-god"; and he made a "bannock" by simply mixing the flour into a stiff dough, allowing it to sour, adding a little soda when he had it, putting it into the spider or skillet in which he had fried his bacon, and setting it before his camp fire to bake. He turned the bannock over once or twice in order to form a thick crust on both sides,

Ward Baking Company

FIG. 78. Bread mixers in a bakery. Each mixer holds dough for 1600 loaves of bread and is operated by an electric motor. Note how the wheels are protected to keep the workmen from being caught in them.

and when the baking was done the traveler and his guide and cook would split the bannock into two parts, insert a few strips of freshly cooked bacon between them, and thus have a dish " fit for a king."

How bread making should be studied. In every manufacturing business today the greatest care is taken to give attention to three phases of the work. In the first place, there are the materials that enter into the manufacture. These are called the raw materials, and they must be thoroughly examined to see that they possess the qualities to fulfill exactly the purposes for which they are to be used. In the second place, there must be a clear idea of the finished product, of what it is that is to be made. In the third place, there must be both a clear

understanding of the steps of the process by which the raw materials are converted into the finished product, and a skilled worker who can carry the process to successful completion. We shall study the three phases of the process of bread making, but during our study we shall not attempt to keep the phases of the subject separate and distinct.

What bread is. Bread is a product manufactured by the process of baking a mixture of flour and water or milk. Salt and yeast are also generally used in the making of bread, and potatoes are often added. If we use the term "bread" in its widest sense, we must also include among our raw materials butter and other fats, eggs, raisins, baking soda, and baking powder.

A cookbook formula for four loaves of potato bread. "Two quarts of warm water, six boiled and mashed potatoes, one tablespoon of sugar, one-half tablespoon of salt, a piece of compressed yeast the size of a pea, and flour enough to produce a thick batter. Beat well together, cover, and set in a warm place to rise. When light, mix thoroughly with sufficient flour for a dough as soft as can be handled. When again risen, mold lightly, put into tins, and set in a warm place to rise. When light, bake one-half hour. If the sponge* is set at tea time, it will be ready to mix by bedtime, and the bread will be ready for the loaves in the early morning." This is one way of telling the story of how to make bread, and the following paragraph* is another.

Aunt Katharine's cookies. "Wal, I takes a yaller bowl, an' de yaller bowl mustn't have no spout. In

dat yaller bowl, I dumps a hunk o' butter, den I th'ows in a good mess o' sugar so dey'll be nice an' crisp, an' I mixes 'em good. Den comes de aigs, — ef dey's cheap, I takes fo'; ef I feels a little close, I takes three; ef dey's dear, I takes two; one'll do well, an' ef dey's very dear, I leaves out de aigs an' don't use no aigs at all. Den I mixes in de aigs or no aigs, dumps in flour, bakin' powder, milk, an' seasonin'. For seasonin', I uses my jedgment — sometimes it's one thing, sometimes another. Den I mixes, rolls, cuts, bakes, an' eats."

Scientific bread making. Neither of these receipts is complete enough for the scientific bread maker. For example, both tell us to use flour, but what is flour? Is it a pure substance or a mixture of several different substances? What is good flour and how shall we be able to distinguish good flour from bad? What is yeast, and what part does it play in bread making? At what temperature will the yeast do its best work? How hot should the oven be in order that the baking may be done properly? What is the effect of adding the potatoes? These and many other questions must be asked and answered before one can claim to have a scientific knowledge of the process of bread making.

What flour is. An experiment will bring to light a partial answer to the question, What is flour?

Exercise 1. Take a small linen handkerchief or square of muslin or cheesecloth, place upon it some flour, bring the corners of the cloth together, and tie them with a string. Hold this bag in a dish of pure water and knead it thoroughly with the hand. The water becomes white with starch from the flour.

Pour the water into a tall, narrow vessel and set it aside. Continue to wash the material in the bag until the water ceases to be made milky; in this way remove all the starch.

By this process the flour has been separated into the starch, which has been washed out by the water, and the gluten, which remains in the bag. Both gluten and starch are valuable foodstuffs. Each of these must now be examined.

Exercise 2. Examine the residue left from the washing of the flour. This is gluten. Note its color. The gluten from good flour is somewhat yellow; that from old and poor flour is grayish. Good flour yields a gluten that is tough and elastic; when pressed in the hand it springs back into its original shape and it is not easily broken into parts. The gluten of poor flour lacks these qualities.

An experienced miller will take some flour in his hand, wash it out in water, and determine whether it possesses the qualities which have just been mentioned. Sometimes he will weigh the flour before washing it and then dry and weigh the gluten he obtains. He then knows the per cent of gluten which the flour yields. How does he compute the percentage? A good wheat flour may contain from 10 to 12 per cent of gluten.

Gluten a protein. Gluten is a protein, the class of foods from which the living material of the body is built. Chemically considered, it contains nitrogen, an element that enters into the composition of all living tissues.

Exercise 3. Take a small amount of water in a test tube. Add a little of the gluten and a few drops of nitric acid (HNO_3), and boil. A yellow color appears.

Add a few drops of ammonium hydroxid [$NH_4(OH)$] and re-heat. The orange color shows that a protein is present.[1]

The outer layers of the wheat grain are richer in gluten than the heart of the grain. It therefore follows that whole wheat flour is richer in gluten than fine white flour, which is made largely from the middle of the kernels. However, dough made from white flour rises more easily than dough made from whole wheat floor, and white bread is usually lighter than brown bread. Different varieties of wheat differ in the amount of gluten they contain.

Exercise 4. Test different foodstuffs for protein, — bread, meat, potatoes, oatmeal, etc. Make a table showing together the results of this exercise and of Exercise 6.

Gluten important in causing bread to rise. Without gluten in the flour it would be impossible to make bread rise. When mixed with water the gluten becomes viscid,* or sticky, and in this condition prevents the escape of gases that may be in the dough. During the baking, part of the water of the bread is converted into steam; there are also carbon dioxid from the yeast or baking powder and bubbles of air in the dough. The heating causes all these gases to expand, and they form little pockets in the sticky gluten, thus causing the bread to rise. During the baking, the walls surrounding these little cavities are hardened, and the openings made by the gases remain in the bread after baking, causing it to be light and porous. What do you suppose happens

[1] Another method of testing for protein is to add sodium hydroxid ($NaOH$) or potassium hydroxid (KOH), and a few drops of a *very weak* solution of copper sulfate ($CuSO_4$). If protein is present, a violet color appears.

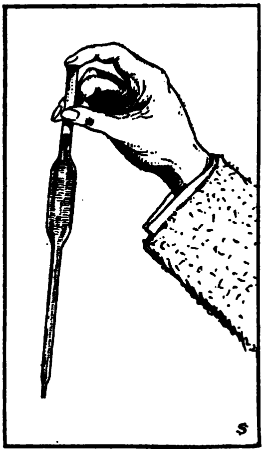


FIG. 79. A pipette of the kind used in chemical laboratories. The liquid is drawn into the pipette with the mouth.

when a cake "falls"? By working small bubbles of air into the dough, "beaten biscuit" are made to rise.

Starch in flour. Starch forms more than one half of the solid matter of grains, such as wheat, rye, oats, and corn, and it is the principal element of flour. The starch left in the water when the flour is washed (Exercise 1) is not dissolved and after a time will settle as a fine sediment in the bottom of the vessel containing the water.

Exercise 5. Remove from the vessel set aside in Exercise 1 the water that is above the starch. This may be done by siphoning off the water with a piece of rubber tubing; or the water may be removed with a pipette without disturbing the starch. Boil some of the starch in water. It seems to dissolve in the hot water into an almost clear liquid, but when it stands and cools it forms a jelly or paste. This is one of the characteristic properties of starch.

Add a small amount of tincture of iodin to some of the boiled starch. The starch turns *blue*. This is a peculiar characteristic of starch, and the presence of starch in any substance may be detected by the use of iodin.[1] Raw starch also is turned blue by iodin, but the action is slower.

[1] The tincture of iodin is prepared by dissolving a small piece of iodin in alcohol. Iodin will not dissolve in water, but a solution may be made

Exercise 6. Test different foodstuffs for starch and record the results in your notebook.

Exercise 7. Scrape a potato, lay a small amount of the scrapings on a glass slide, add a drop of water, place over it a cover glass, and examine it under the microscope. The starch grains may be clearly seen.

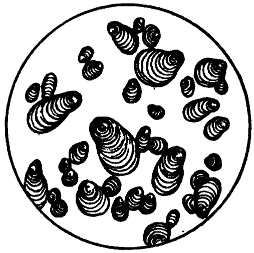


Fig. 80. Grains of starch as seen under the microscope.

Starch grains from different plants vary in size and form, so that the source of starch can be determined by examination under the microscope.

Dextrin. When starch is heated, as in the baking of bread, the molecules are broken up into a substance known as dextrin, which is somewhat sweet to the taste. Dextrin is found in the crust of bread. It is a gum, and great quantities of it are used in the manufacture of mucilage. It is used on the backs of postage stamps and in sealing envelopes. In the crust of the bread some of the dextrin is still further changed to caramel.

How starch is used by the body. First the saliva changes the starch into dextrin, and then the dextrin is still further broken up into a sugar. The sugar is readily soluble in water and can be absorbed into the blood and distributed to all parts of the body. The great use of sugar in the body is to furnish heat and to give energy to the muscles, while the proteins are the foods that are

by dissolving potassium iodid in water and then dissolving the iodin in this solution. Two parts of iodin and 15 parts of potassium iodid to 100 parts of water will make a solution of the right strength.

used in building the cells and tissues of the body. It will thus be seen that bread furnishes to the body both building material and energy.

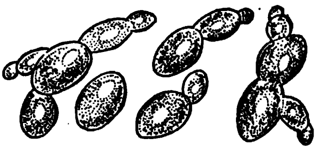


FIG. 81. Yeast plants as seen under the microscope.

Yeast and its action. The yeasts are a group of living plants, all so small that they can be seen only by the use of a microscope. Each plant consists of but a single cell. They feed upon sugar and starchy materials and also require that a part of their food shall contain nitrogen. They grow and multiply very rapidly. As they grow, they produce a certain substance which has the curious effect of changing sugar into alcohol and carbon dioxid. The chemist would write the story of the change which the yeast produces as follows:

$$\underset{\text{sugar}}{C_6H_{12}O_6} \rightarrow 2\ \underset{\text{alcohol}}{C_2H_5OH} + 2\ \underset{\text{carbon dioxid}}{CO_2}$$

In bread making the carbon dioxid given off by the yeast is the most important factor in causing the dough to rise. The bubbles of the gas are caught by the elastic gluten of the flour and held long enough to expand the dough to double its size or more. Before the end of the baking, the gas as well as the alcohol vapor escapes, leaving the bread light and porous. When eggs are added to bread they assist in the rising of the bread by making the dough or batter tough and sticky so that it will hold the expanding gases. Very commonly, too, air is beaten into the eggs before they are added to cake or bread.

The best temperature for the growth of yeast. The dough must be kept at a temperature that will allow the yeast plant to grow, or the baker will fail in the raising of his bread. These little plants thrive best between the temperatures of 70 and 90 degrees F. They are completely destroyed when the temperature rises above 131 degrees; if the dough is overheated, the bread does not rise and is sour and unpalatable. Without a thermometer, how could we keep the sponge* between the temperatures of 70 and 90 degrees F.? In order to cultivate your judgment in this direction, try the following exercise:

Exercise 8. Pour into a vessel a cupful of boiling water and a cupful of water at the temperature of the laboratory or kitchen. Take the temperature of the mixture. Find, by trial, how much boiling water must be added to a quart of water at ordinary temperature to bring the mixture to a temperature between 70 and 90 degrees F. Should boiling water be poured directly into dough?

In baking, of course, the temperature goes much above 131 degrees F., and in consequence the living yeast plants are destroyed and cease to produce carbon dioxid. The temperature of the large commercial ovens rises to a temperature of 400 or 500 degrees F. In the ordinary oven the temperature is somewhat lower than this, about 380 degrees F. As long as moisture remains in the bread, the temperature of the interior of the loaf will not be above that of boiling water.

The use of potatoes in bread making. Potatoes are often used in the making of bread. Not only do they

give their own peculiar flavor to the bread, but they also furnish materials which greatly stimulate the growth of the yeast plants. Because of this, less yeast may be used when potatoes are included in the sponge.

Exercise 9. Dissolve thoroughly about $\frac{1}{16}$ of a cake of compressed yeast in a small amount of tepid* water; add to it a very small amount of ammonium chlorid and a tablespoonful of molasses, and pour the mixture into a large-sized test tube which is provided with a delivery tube. Add warm water enough to make the test tube three quarters full. Put the tube in a warm place, — where the temperature will be between 70 and 90 degrees F.

Pass the gas which comes from the delivery tube into a solution of limewater. After a time (perhaps an hour or two) the limewater will be seen to contain a milky sediment (page 109). What does this prove? By appropriate apparatus it is possible to separate out the alcohol which is produced at the same time as the carbon dioxid.

Exercise 10. After a few hours mount on a slide a drop of the liquid in which the yeast is growing and examine it with a microscope.[1] It will be found to contain hundreds of small yeast plants. How do they multiply? The yeast will be more clearly seen if the drop of liquid examined is taken from the upper part of the tube without stirring up the fragments of the yeastcake.

The only reason for using yeast in bread is to produce carbon dioxid to make the bread rise. It is a great advantage to have bread light and filled everywhere with small pores, for then the digestive juices can gain easy

[1] Yeast for examination may be grown very easily in a solution of sugar in water.

access to every part of it and thus act quickly and readily on it.

Helping the growth of the yeast. Sometimes yeast-cake has a disagreeable flavor and odor, and if a large amount of it is used in starting the bread the objectionable taste may be detected in the loaf after it has been baked. Scientists have been making careful studies of how the yeast in the bread can be made to multiply more rapidly so that only a small amount of yeastcake need be used, and recently they have announced that a very little ammonium chlorid in the sponge greatly helps the growth of the yeast. It is also very important that the dough be thoroughly kneaded, so that the yeast may be mixed into all parts of it.

Substitutes for yeast. Partly because yeast is sometimes poor and does not do its work well, but more particularly because it feeds upon and thus uses up some of the valuable food materials of the sponge, other substances often are used to produce carbon dioxid in bread. Liebig, a great chemist, calculated that in Germany the daily loss of good food material by the growth of the yeast plant was sufficient to supply 400,000 persons with bread. There are numerous baking powders which are used as substitutes for yeast. Any substance that is used for the raising of bread should yield a good supply of carbon dioxid and should not leave harmful products in the bread. The chief objections to the use of ordinary baking powders are that they may be adulterated or badly prepared and therefore inefficient, and that disagreeable or unwholesome products from them may remain in the

bread. In any case, they lack the flavor and aroma which good yeast imparts, and yeast bread is still the kind that is most commonly made.

Baking soda. Common baking soda, better known as carbonate of soda ($NaHCO_3$), may be used to produce carbon dioxid. When mixed in the dough and heated, it yields the gas; but in this case there remains in the bread sodium carbonate, an alkaline substance which renders the bread unwholesome. The chemical reaction is

$$\underset{\text{sodium bicarbonate}}{2\,NaHCO_3} \rightarrow \underset{\text{sodium carbonate}}{Na_2CO_3} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxid}}{CO_2}$$

Exercise 11. To a water solution of baking soda add a few drops of hydrochloric acid. Test the gas that is given off, by passing it into limewater.

$$\underset{\text{sodium bicarbonate}}{NaHCO_3} + \underset{\text{hydrochloric acid}}{HCl} \rightarrow \underset{\text{sodium chlorid}}{NaCl} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxid}}{CO_2}$$

This experiment illustrates a method which is used, with many variations, to raise bread. For example, a light bread or pancakes may be made by the use of baking soda or sour milk. If two teacups of sour milk be added to the flour and one teaspoonful of soda be well mixed in just before baking, a copious amount of the gas is produced and the bread is light. In this case there is left in the bread a compound, sodium lactate, which is harmless. The milk has contributed some good ingredients to the bread. Care must be taken not to use too much soda, or the bread will be yellow and unwholesome.

Gingerbread. This very palatable form of bread is made by the use of baking soda and molasses, the acid of

which, acting upon the soda, produces the gas. In case the molasses is not sufficiently acid, a little sour milk or vinegar may be added to it before it is mixed with the flour.

FIG. 82. A review of bread making.

Baking powders. Among the best agents for the raising of bread without the use of yeast are combinations of baking soda with substances that are acid in their nature. The one most commonly used and giving the best results is that known as cream of tartar. The soda and the cream of tartar do not act upon each other as long as they are kept dry, but they react quickly when dissolved in water. For this reason, the cream of tartar and the soda should be mixed with the flour before any water is added. The substance which is left in the bread is known as "Rochelle salts." The equation which tells the story of what happens in the dough is as follows:

$$NaHCO_3 + KHC_4H_4O_6 \rightarrow KNaC_4H_4O_6 + CO_2 + H_2O$$
$$\text{soda} + \text{cream of tartar} \rightarrow \text{Rochelle salts} + \text{carbon dioxid} + \text{water}$$

Exercise 12. In separate glasses dissolve small amounts of baking soda and cream of tartar in water. Pour one solution into the other. Violent chemical action takes place and carbon dioxid is given off.

In the baking powder that we buy in the stores, the baking soda is mixed with the cream of tartar, along

with flour or starch to absorb moisture. It must be kept perfectly dry until it is to be used. Why?

Salt-rising bread. In making salt-rising bread, the housewife mixes corn meal with hot water or milk, and adds salt and a little soda. After some hours this mixture ferments and carbon dioxid is given off. It is then added to dough in place of yeast and the dough is made up as for ordinary bread.

It has been discovered that it is a certain kind of bacterium, and not yeast, that grows in this mixture and gives off carbon dioxid. The bacteria get into the mixture from the corn meal and grow best when milk is used in making up the batter.

A practical review. For a review of this chapter, get your mother to allow you to go through the interesting process of bread making. Follow directions closely and give a reason for each step that you take. Are you finding that science is closely related to the everyday work of life?

CHAPTER FIFTEEN

THE LIMESTONE STORY

MAKE a field excursion for limestone. This excursion may be taken after school on a favorable afternoon, on Saturday, or under the direction of the teacher during school hours. It may be taken by the whole class together or by individual members. Much enjoyment as well as profit may be derived from excursions of this kind. Having a definite object emphasizes and gives point to the recreation.

Carry with you on your excursion a knife (an old one will do) and a small vial of hydrochloric acid, which you may obtain at any drug store. A geologist always carries a strong hammer on his field trips, and it might be well for you to take with you this useful article. Read this chapter over carefully before you start, or carry your book with you on your collecting tour.

Exercise 1. Look for stones that (1) are white or gray in color, (2) are easily scratched with a knife, and (3) give off bubbles of gas when touched with a drop of acid.

If you succeed in finding a mineral that meets these three tests and is about one third as heavy as iron, you may conclude that it is limestone. Take some good-sized pieces home with you for study.

Crystallized limestone. Sometimes, but not always, a piece of limestone will show bright surfaces that glisten in the sun. This is due to crystals in it. When highly crystallized, limestone is transparent* and breaks easily and smoothly in three directions in surfaces which are nearly at right angles to each other. Pure

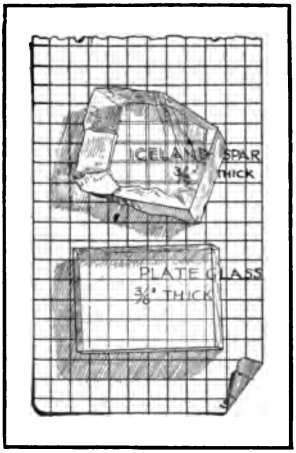


FIG. 83. A crystal of Iceland spar forms a double image of an object that is seen through it.

crystallized limestone is known as Iceland spar, because very perfect crystals of the mineral are formed from the waters of the geysers* and hot springs of Iceland.

Iceland spar has the very remarkable property of double refraction; that is, it forms two images of an object that is looked at through it. If you place a piece of Iceland spar on a printed page, you will see two images of every letter.

The composition of limestone. We are now to learn the chemical composition of limestone, to answer the question: Of what is it made? If you were not successful in finding any limestone on your excursion, you can go to a marble shop and get some fragments of marble. This is limestone that is composed of very fine crystals. It has been subjected to great heat in the earth and has crystallized in cooling. See that it agrees with all the tests for limestone as given in Exercise 1.

Exercise 2. Take two test tubes; two small vials or bottles will answer. In one tube place a small piece of limestone and in the other limewater to the depth of one inch. Add a few drops of acid to the limestone. Notice the gas which is given off. It is heavier than air and can be poured like water from one tube into the other. Hold the

tubes so that the gas which comes from the tube containing the limestone will settle into the one containing the limewater.

After the gas has been running a minute or two, put your thumb over the mouth of the tube containing the limewater and shake it to mix the limewater and the gas together. A precipitate appears in the limewater. What does this indicate (Exercise 7, page 108)? Was there carbon dioxid in the acid that you used?

We have learned that limestone gives off carbon dioxid, and we may conclude that it is in part composed of carbon and oxygen. We have also learned why limestone effervesces when it is touched with an acid.

Exercise 3. Place pieces of limestone or marble of the size of a hickory nut on the top of a coal fire, in the oven of a stove, or on a piece of wire gauze over a low flame and let them stand for some time. Examine a piece which has been treated in this way. Notice that it has become soft and brittle. Test it with the acid. If sufficiently burned it will not effervesce. It is no longer limestone. By heating, the limestone is changed into quicklime, or lime, as it is commonly called.

Exercise 4. Place some of the limestone in an ignition tube provided with a suitable delivery tube and pass into limewater the gas which is given off. A white precipitate is formed. What does that fact indicate? Review the exercises on page 109.

Let us understand clearly what has happened. The chemical name of limestone is calcium carbonate. Its formula is $CaCO_3$. The heat has weakened the union between the different elements of the limestone, and carbon dioxid has been driven off. All the carbon and

part of the oxygen pass off into the air as carbon dioxid, leaving the calcium and one atom of oxygen behind in the form of quicklime, or calcium oxid.

$$CaCO_3 \rightarrow CaO + CO_2$$
$$\text{limestone} \rightarrow \text{quicklime} + \text{carbon dioxid}$$

How to write a chemical story. A chemical equation is a history or story of a chemical transaction. It is the chemist's way of telling what happens when a chemical change takes place. An important point to remember in writing a chemical equation is that all cases of chemical action follow the law of conservation of matter. Hence, the equation must show what has become of every atom that entered into the action. We may think of a chemical action as a battle and the atoms as the soldiers; but after the chemical battle is over every soldier that entered the fight is still on the field. Can you explain what becomes of all the atoms when limestone is heated?

A study of quicklime. Use the quicklime produced in Exercises 3 and 4, or get some from a dealer. It must be fresh and in lumps; air-slaked lime will not do for your experiments. Any lumps that are to be preserved must be kept in dry, tightly stoppered bottles.

Exercise 5. Place some of the lime in a dish and drop some rainwater or distilled water slowly upon it. Notice the hissing sound, the steam which rises, and the heat which is produced.

The fact that heat is produced is proof to the chemist that there has been chemical action between the lime and the water. The story can be told in this way:

$$CaO + H_2O \rightarrow Ca(OH)_2$$
$$\text{lime} + \text{water} \rightarrow \text{slaked lime, or calcium hydroxid}$$

Exercise 6. Continue the addition of water to the lime used in the last exercise until most of the lime has been dissolved. Allow the solution to settle and put the clear liquid into a clean bottle. Stopper the bottle tightly and label it Limewater, or $Ca(OH)_2$.

FIG. 84. The carbon dioxid unites with the limewater to form limestone.

Manufacturing limestone. We produced lime by driving carbon dioxid out of limestone (Exercises 2 and 3). Then we added water to the lime and formed a compound of the lime which dissolved in the water (Exercises 5 and 6). What would happen if we should again add the carbon dioxid to the limewater? This you have already done in many experiments, and, as you know, a white precipitate is formed. This precipitate is limestone; the carbon dioxid and the lime compound reunite and form fine particles of limestone (shall we call them little stones?) which give a white appearance to the water.

$$\underset{\text{limewater}}{Ca(OH)_2} \quad \underset{\text{+ carbon dioxid}}{+ \quad CO_2} \quad \underset{\rightarrow}{\rightarrow} \underset{\text{limestone}}{CaCO_3} \underset{+}{+} \underset{\text{water}}{H_2O}$$

Exercise 7. Breathe through a glass tube or a straw into a test tube of limewater. You are now operating a limestone factory. In what two ways could you again break up this limestone into carbon dioxid and lime?

Now review Exercise 4. In one test tube, the limestone is decomposed and the carbon dioxid is given off;

in the second tube the carbon dioxid unites with the limewater to recompose* limestone. In the one tube you were breaking up limestone; in the other you were making it again. Do you know how lime is manufactured and what happens to it if it is exposed to the air?

Chemical changes in mortar and whitewash. Slaked lime mixed with sand makes mortar for plastering and bricklaying. When mortar is exposed to the air, it gradually takes up carbon dioxid from the air and the lime in it is changed to solid limestone again. Slaked lime with water is used for whitewash. This takes up carbon dioxid from the air and forms a thin coating of limestone over objects that are whitewashed.

Uses and forms of limestone. Limestone is extensively used in the manufacture of iron; millions of tons of it are burned each year to produce lime; it is ground and spread on agricultural lands to destroy the acid in them; and when ground fine, mixed with clay, and burned, it forms the compound known as "Portland cement." Some limestones contain cracks and fissures* along which they can be split. Limestone of this kind is much used for building stone, flagstones for sidewalks, and other purposes.

Marble is a limestone which is crystallized, compact, and fine grained. It will take a high polish, and is used for statuary, tombstones, table tops, mantels, and floors.

In some countries there are deposits of a soft, friable* limestone which is known as chalk. It is composed of the shells of small animals. What is the difference

between chalk and crayon? Why is England sometimes called "old Albion"?

Pearls are rounded masses of limestone found on the interior of oyster, mussel, and other bivalve* shells. They are formed of mother-of-pearl, — the same substance which lines the inner surface of the shells. Very small parasitic worms infest the oyster and the mussel, and when one of these worms dies in the body of the animal it is incased in mother-of-pearl. A French writer has said, "The ornament associated in all ages with beauty and riches is nothing but the brilliant sarcophagus* of a worm."

Marl is a soft and granular form of carbonate of lime found at the bottom of some fresh-water lakes and on their shores. It is generally mixed with more or less clay.

Deposits of marl. In the northern part of the United States there are thousands of fresh-water lakes, and in the waters of these lakes there grows a small plant (*Chara**) which takes limestone out of the water and with it builds a crust over itself. Where these plants have been growing for centuries, there have been formed from their skeletons great deposits of marl. Animals, like the oyster, that build shells also take limestone out of the water, and marl deposits may be formed from beds of shells. Marl in beds of great thickness is found not only in and near our northern lakes, but also in the valleys of some of our large rivers, — the Mississippi, Missouri, Colorado, and Alabama, — along the shores of Chesapeake Bay, and in many other parts of the United

States. These beds are of great value for the manufacture of Portland cement.

Exercise 9. If there is a lake near you, bring up material from the bottom. If this is white after drying, it is probably marl. Do the marl deposits extend out under the marsh land near the lake? If there are marl beds of any kind in the vicinity, bring samples of them to school.

Test the samples with acid. A good marl will effervesce when treated with an acid. Rub a little of the marl between the fingers and also take some upon the tongue. If it feels "gritty," it is probably mixed with sand and would not be the best kind for making cement.

Measuring the amount of marl in a deposit. To be profitable for cement making, a marl bed should be of at least 100 acres, with an average depth of from 15 to 20 feet of good marl. In case you have found what seems to be a good marl deposit, you may be interested in learning how to estimate how much marl is available. To do this the land is laid off in squares of 10 rods each way, and two facts are ascertained: (1) the depth of the rock or soil over the marl (in order to estimate correctly the cost of removing, or "stripping off," the soil), and (2) the depth of the marl. An auger about an inch and a half in diameter and attached to a long rod may be used to test the depth of the marl. The rod may be made of three-quarter-inch gas pipe cut into pieces 5 feet long and jointed together. A paper laid off in squares will serve as a map of the land that is being tested. As each hole is bored a record of the findings is entered on the map.

Clay for cement making. The other constituent of Portland cement is clay. There is no easy way by which good clay can be determined, and specimens must be sent to some competent* chemist. When placed upon the tongue, it should feel smooth and "soapy" but should not show any grit. When pure clay is mixed with water and then dried, it becomes very hard. The author, when a boy, made very good marbles in this way.

For what purposes is Portland cement used? How many miles of cement sidewalks are there in your town? What does it cost per square yard to build such walks? How much money, therefore, is invested in such walks in your town?

Fig. 85. Limestone deposited by water trickling down the side of the Luray Caverns.

Caverns in limestone regions. Limestone is dissolved by water, and in limestone regions it is not uncommon for streams to run underground in caverns that they have made for themselves in the rocks. The great Mammoth Cave in Kentucky and the beautiful Luray Caverns in Virginia were formed in this way. In Florida large underground rivers reach the

sea through channels in the soft limestone of which a considerable part of that state is formed.

Exercise 10. Breathe through a glass tube or straw into a tube of limewater. At first calcium carbonate is precipitated. Continue breathing carbon dioxid into the water. After the water becomes heavily charged with carbon dioxid, the calcium carbonate is dissolved and the liquid again becomes clear.

Water which penetrates deep into the earth takes up carbon dioxid, and this greatly increases its power to dissolve limestone (page 67). Can you explain how the sparkling limestone crystals which make the Luray Caverns and many other caverns so beautiful are formed?

The formation and occurrence of limestone. Limestone composes one eighth of the earth's crust. Sometimes it is found in deposits of marl, coral rock, or chalk; sometimes in massive beds hundreds or even thousands of feet thick. Where did this limestone come from? It is laid down from water in various ways. Animals like the oyster and other mollusks take the limestone from the water of the sea to build their shells; the coral polyp builds up great ledges and reefs of limestone from materials that it takes from the sea; many very minute marine* animals build shells that sink to the bottom on the death of the animals and slowly form layers of limestone; and from the ocean's waters vast amounts of calcium carbonate are precipitated to make great beds of limestone in the depths of the sea. In time part of this limestone is raised to form land, and then is again dissolved and carried by the running water to the sea.

CHAPTER SIXTEEN

A FIELD EXCURSION FOR MINERALS

READ the first part of this chapter over carefully before you start on your excursion; then take the book with you, find some comfortable place to sit down, and read it again.

On a preceding field excursion you went out to look for limestone. This time it may be for another class of minerals. You will need to take along several things: do not forget your eyes — you will need to have them wide open at every step; you will need an old knife, for you can identify minerals by their hardness more easily than by any other quality; you will need your little bottle of hydrochloric acid in order to note its action on the various minerals you may find; and you should have a hammer and a small piece of window glass. If in addition you have enthusiasm, you will find it a great pleasure to go out to ask questions of Mother Nature. On the whole, you will not have so much trouble this time to find what you want as you had in the excursion for limestone, although, of course, the difficulty of the search depends upon the particular region in which you live.

Exercise 1. Go out into the open fields, or along a railroad cut, a gravel pit, or the shore of a lake. Look for minerals answering to the following description:

(1) So hard that they cannot be scratched with a knife; so hard that the sharp edge of a fragment will scratch the window glass.

(2) Sometimes transparent or translucent,* but generally of a uniform dull color; brown, yellow, red, or gray. Some-

times there are different colors in rings or bands; sometimes the mineral looks soft, like wax, and yet is very hard.

(3) When broken into pieces, showing surfaces that are never smooth and glistening. If you are told that frequently the broken surface is conchoidal,* will you look that word up and see what is meant by it?

(4) Generally rounded and smoothed; such specimens are often found as pebbles.

If you have found minerals that have the above properties, you have doubtless obtained specimens of what is known by the general name of quartz. Quartz is the hardest of all common minerals, and if you find a specimen on which the knife leaves a dark streak of iron, it is surely quartz. The chemical name of quartz is silicon dioxid (SiO_2). It is a compound of silicon, an element that is abundant in compounds but is very rare in its elementary form. Ordinary sand is finely divided quartz, and sandstone is particles of sand bound together by some cementing substance.

Exercise 2. After you get home take your Bible and read the twenty-first chapter of Revelation. Look for the minerals that are mentioned there and make a list of them. For the most part they are all varieties of the mineral quartz. Look up their proper pronunciation and interesting facts concerning them in the dictionary or encyclopedia.

It is desirable to have access to a good collection of quartz. No other mineral is found in so many beautiful forms as this. Some of the more common forms are described below, and in the list you may find some of the specimens that you have gathered. Bear in mind

FIG. 86. "Crystal gazing." It was formerly believed that an alchemist could read the future in his crystal globe.

that every mineral in the following list is simply a variety of quartz, and that each one possesses the qualities that you looked for in making your collection.

Rock crystal. Pure pellucid* quartz. When the crystals are separate, they may be known by their form, which is almost always that of a six-sided prism terminated with six-sided pyramids (Fig. 52). The ancients applied the word *crystal* to this mineral; it is from a Greek word, *krustallos*, meaning ice. In spite of its hardness, pure specimens of quartz are often cut into jewelry. Rock crystal is also used for optical instruments and spectacle glasses. Even in ancient times it was cut into cups and vases. Nero,* on hearing of the revolt that caused his ruin, is said to have dashed to pieces two cups made of this material. It was formerly believed that certain persons could read the future by steadfastly gazing into a globe cut from pure rock

crystal, and " crystal gazing " is still sometimes practiced as a sport.

" Brazilian pebbles " and " Alaska diamonds " are merely crystalline quartz.

Amethyst. Purple or bluish violet. This is one of the most beautiful varieties of quartz and is highly esteemed as a gem.

Rose quartz. Pink or rose colored. Does not usually crystallize. Not much used for ornamental purposes, as the color fades.

False topaz. Light yellow crystal. Often cut and set for real topaz, which is quartz combined with aluminum and fluorin.

Smoky quartz. Crystals of a smoky tint; color sometimes so dark as to be nearly black.

Milky quartz. Milky white, nearly opaque, and of common occurrence. Has often a greasy luster.*

Chalcedony. Translucent, with a waxy luster, looking as if it could be cut with the finger nail. It often fills cavities in other rocks. Chalcedony containing minute mossy patches of a darker color is moss agate.

FIG. 87. A cameo.

Agate. A semipellucid,* uncrystallized variety of chalcedony which has various colors in the same specimen. The colors are arranged in bands or there may be a cloudy effect.

Chrysoprase. Apple-green chalcedony; colored by nickel.

Carnelian. Bright red chalcedony, of a rich clear tint. Much used in jewelry.

Onyx. A variety of agate in which the colors are arranged in flat, parallel layers. Usually one of the colors is white; and when an emblem or figure is carved out of one color with the other as a base, a cameo is produced.

Flint. Dark shades of smoky gray, brown, or even black, translucent on thin edges, breaking with sharp edges and a conchoidal surface. Indian arrowheads are made from this variety of quartz.

U. S. Geological Survey

Fig. 88. Silicified tree trunk in the Yellowstone National Park.

Jasper. A dull opaque red, brownish, or greenish quartz. Can be highly polished. It will be quite easy to find good specimens of jasper in any of the Northern states.

Bloodstone or Heliotrope. Deep green, slightly translucent, containing spots of red due to a small percentage of clay and iron oxid. In the royal collection in Paris is a bust of Christ cut from this stone in such a manner that the red spots appear as drops of blood.

Opal. Colors — white, yellow, red, brown, green, blue, and gray. A good specimen will show a rich play of colors when turned in the hand.

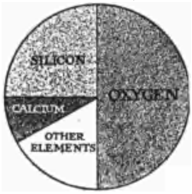


FIG. 89. Diagram showing the amounts of different elements in the earth's crust

Silicified wood. Petrified* wood often consists of quartz which has taken the place of the original particles of the wood.

Quartz in the earth's crust. One more statement will show the importance of the substance which we have just studied. The crust of the earth, as we know it, is 18 or 20 miles thick. Three quarters of it is made of either pure quartz or its compounds. If we should represent by a circle the materials of which the crust of the earth is composed (Fig. 89), one half of the circle would represent oxygen; for one half of the outer layers of the earth is oxygen. One half of the remaining half, or one quarter of the whole, is the element known as silicon. But the silicon is combined with oxygen to form quartz, so that the greater portion of the surface layers of the earth is composed of the mineral which has been the object of this study. One third of the remaining fourth of the crust of the earth is the metal calcium, which is most often combined with carbon and oxygen to form limestone. All other chemical elements, as is shown by the diagram (Fig. 89), form but a small proportion of the outer layers of the earth.

CHAPTER SEVENTEEN

LOOKING FOR ROCKS

FIG. 90.

EXAMPLES of minerals have been studied in the limestone and quartz. These and all other minerals have a definite chemical composition. Thus limestone is calcium carbonate ($CaCO_3$), agate is silicon dioxid (SiO_2), diamond is crystallized carbon (C), the ruby and the sapphire are oxids of aluminum (Al_2O_3), iron ore is an oxid of iron (Fe_2O_3), common salt is sodium chlorid (NaCl).

Rocks, on the other hand, are mixtures of two or more minerals. They are to be recognized, usually, by the fact that to the eye they present various colors or differences in structure in different places in the rock. They are not homogeneous,* as the scientists

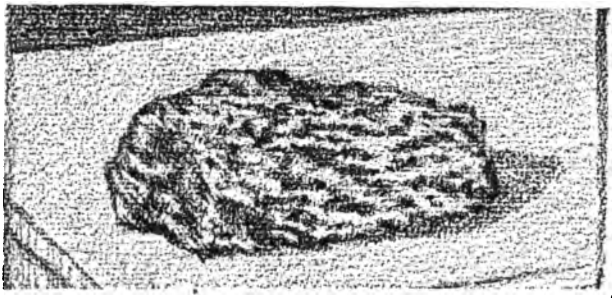


FIG. 91. The structure of granite.

would say. What word should you apply to them if they are not homogeneous?

Granite. One rock with which nearly every one has an acquaintance is granite. This is a mixture of three minerals: quartz, feldspar, and mica. It may be seen in the stone fences and bowlders which are to be found everywhere in all the states north of a line approximately following the Ohio and Missouri rivers. Coarse granite may easily be recognized by the black or golden flakes of mica embedded in a mixture of white or gray quartz and flesh-red or pink feldspar. Look for three colors, all more or less intermingled, — dark specks and scales on a grayish and pinkish background.

Quartz. You have already studied quartz and will be able to recognize it by its peculiar qualities. In granite its color is usually white or gray; it is so hard that it will scratch glass and cannot itself be scratched with a knife. In the granite the quartz mineral is generally in rounded grains or pebbles. Sometimes these are so closely crowded together that their outlines

cannot easily be separated from the other minerals in the rock. In coarse granite this can easily be done.

Feldspar. Is there a light-colored, pinkish, reddish, or flesh-colored part of the granite, which can be scratched with a knife, although possibly with some difficulty? It is probably feldspar. Quartz will scratch feldspar; but feldspar will not scratch quartz. If there is difficulty in deciding whether a given mineral is feldspar or quartz, there are several ways to find out which it is. First examine it as to its luster, its power to reflect the light. Quartz looks like broken glass; feldspar has a pearly luster. Compare your specimen with a piece which you know to be pure quartz.

Next, notice whether the mineral shows anywhere a tendency to break into flat surfaces along two directions that are nearly at right angles to each other. Quartz never presents flat surfaces or faces; feldspar presents two such faces. Again, these flat surfaces of the feldspar, when held in the sun, reflect the light. By this sign we can be fairly sure of feldspar. Gather a number of specimens, choose the coarsest ones, and do not be discouraged if you cannot at once and clearly distinguish between quartz and feldspar.

Mica. Usually mica is of a dark or black color and may be split into small, flat scales which reflect the light and glisten in the sun. If the surfaces are brilliant, the scales are generally elastic; but sometimes we find that they have lost their elasticity.

Mica is found in some places in large masses that will split into thin, tough, flexible, elastic scales. In that

form it is extensively used in stove doors. Ask the hardware man for some scraps of mica.

Iron pyrites. Sometimes the granite is in the process of being broken up by the action of water, especially when the water freezes. This is often due to the presence of small particles of iron pyrites, or "fool's gold," as it is sometimes called, which is a compound of iron and sulfur. The action of the oxygen of the air renders pyrites somewhat soluble in water, and granite that contains it is sometimes quite broken up by exposure to the weather. Pyrites is easily recognized, as it shines like gold when held in the sun.

Sometimes you may be curious to know whether these shining golden particles are not really gold. Pure gold rarely occurs in masses large enough to be seen by the unaided eye, and a chemical test that will distinguish iron pyrites from gold is easily made. Strong hydrochloric acid applied to the pyrites will give the odor of hydrogen sulfid (H_2S), — the well-known odor of decaying eggs. This acid has no effect upon pure gold. Heating the pyrites over a hot flame will give the odor of sulfur dioxid, — the familiar odor of burning sulfur.

Occurrence and uses of granite. Much of the deeper part of the earth's crust is granite, and many vast mountain chains are granite. It is one of our hardest and most enduring rocks except when it contains other minerals besides quartz, feldspar, and mica, such as the iron pyrites mentioned above. Notwithstanding the difficulty of working it, granite is used for monuments and building purposes, because it so well withstands

U. S. Geological Survey

FIG. 92. A granite mountain in Georgia.

the crumbling hand of time. In cemeteries may be seen polished granite monuments which show clearly the structure of the rock.

Other rocks. The rocks which make up the earth's crust are of many different kinds. Besides granite, which we have studied, sandstones, shales, and volcanic rocks cover great portions of the surface of the earth. You will observe and study these with more interest if you understand how they are formed. They are divided according to their origin into two great classes, igneous* and sedimentary* rocks.

Igneous rocks. Granite is an igneous rock. It is a part of the original molten matter of which the earth was

FIG. 93. A lava field in the Hawaiian Islands.

formed. Volcanic rocks also are igneous rocks; they are formed from lava which has been poured forth from volcanoes and which, in ages past, flowed, in some parts of the earth, through cracks in the earth's crust. Much of the surface of a number of our Western states is covered with volcanic rock; many of the islands of the Pacific Ocean (the Aleutian Islands, Japan, the Philippines, the Hawaiian Islands, and many others) have been built by volcanoes; and a large part of southern Idaho is covered by a sheet of lava which welled up through a great fissure along the mountains on the eastern border of the state and flowed westward in a vast flood. Another example of igneous rocks is found in the famous Palisades of the Hudson River. These were formed from material that came up through a crevice in the earth and crystallized into great columns as

U. S. Geological Survey

FIG. 94. **The Palisades of the Hudson.**

it cooled. Igneous rocks cover about one tenth of the surface of the earth, and wherever there are sedimentary rocks, igneous rocks underlie them.

Sedimentary rocks. In any part of the United States it is easy, after a long and heavy rain, to find places along the banks of creeks or rivers where the water has overflowed the land. In time the flood will recede or seep into the earth, and after that has taken place you will see a thin film of muddy slime covering the surface of the ground. Thousands of people who live on the lowlands bordering the Ohio River, for example, look with great anxiety to the time when the spring rains will melt the accumulation of the snows of winter. The river then overflows its natural banks and the muddy water covers every place where it stands — streets, cellars,

and sometimes the houses — with a thick deposit of mud. Where did the mud come from? Evidently from the land lying on the hills and high ground along the borders of the creek or river. All through the long period of time during which this stream has existed, soil has been transferred from the hillsides to the valley.

Suppose this has been going on along our rivers for thousands of years. You can understand how in the course of time a tremendous amount of material has in this way been transferred to the lower land and deposited at the mouths of rivers in the sea (page 170). This is one of nature's methods of making land, and you can find proof everywhere that lakes and the ocean at the mouths of rivers are slowly filling up, leaving finally a low, level deposit of soil. What is the deposit of land at the mouth of a river called?

The process by which the hills and banks of streams are worn down is called erosion.* The material that is carried by the water is called sediment.* The process of depositing this material is called sedimentation.

It is not difficult for us to understand how the soft earth is finally changed to solid rock. We have only to take into account the element of time. The time that the rivers of the earth have been at work has been long, — many millions of years, — so that inevitably some of the layers of sediment that were first laid down became pressed upon by thousands of tons of deposits above them. This pressure, together with the effect of the internal heat of the earth, finally compacted the sedi-

FIG. 95. Stratified rock.

ment into solid rocks. Why are these rocks called "sedimentary rocks"?

The material that is washed down by streams is deposited in layers, and when the sediment hardens the layers may still be seen. These are called strata (singular, *stratum*); the rocks are said to be stratified. Such stratified soil and rocks may often be seen in railroad cuts, gravel pits, or stone quarries, or stratification may be observed by cutting through the layers of material that have been deposited along the course of a stream.

Fossils. Any shells or skeletons of animals or the remains of plants that became buried in the mud and their forms pressed into the rock as it was being formed, are known as fossils (Fig. 88). In certain regions you may easily find in the stratified rocks the remains of animals that lived ages ago. The fossils of the gigantic animals that roamed the earth millions of years before man made his appearance are one of the great sights that a modern museum offers.

Sandstones. Sandstones are good examples of sedimentary rocks formed from the wastes of such rocks as granite. By the action of the air and moisture, together with alternating freezing and thawing, the feldspar is changed to clay and washed away to form soil. The quartz is left as sand and is washed into the sea or into a lake, where it spreads out in layers. Then the grains of sand are cemented together by some mineral like limestone that is deposited from the water. In this way great beds of sandstone are formed. Red sandstone is cemented together with oxid of iron, and because the cement is not affected by the oxygen of the air this kind of sandstone makes a most durable building material. Why is iron oxid not attacked by oxygen?

Shale. When the clay and other fine-grained sediment which is carried by rivers and smaller streams is deposited, the rocks formed from them are known as shale and slate. Shales are generally gray to black in color, but sometimes of dull greenish, purplish, reddish, or other shades. Often they split into very fine layers. When shale is weathered,* a clay soil is formed.

Slates are dark, fine-grained, and hard, and split very evenly. The best quality of slates are sometimes split into roofing slate or writing slate.

Is limestone an igneous or a sedimentary rock?

CHAPTER EIGHTEEN

THE SOIL

FIG. 96.

Go out into an open field, stand still, and ask yourself what it is you are standing upon. The most evident answer you could make is, "I am standing upon the earth"; you might say, "I am actually in contact with Mother Earth." If you said *old* Mother Earth, your expression would not be considered disrespectful, for the earth is very old. Some day you will study geology, that science which deals with the earth as a whole, its origin, its history through the countless millions of years which elapsed before man came to live upon it, its age, and something of its future destiny. But without waiting for that time, you ought, here and now, to have some general ideas concerning the earth.

The horizon. There is the horizon,* circular in form and usually seeming to be higher than the place where you are standing. You will recall, in this connection, the facts learned in geography concerning the shape of the earth, the shadow of the earth on the moon at the

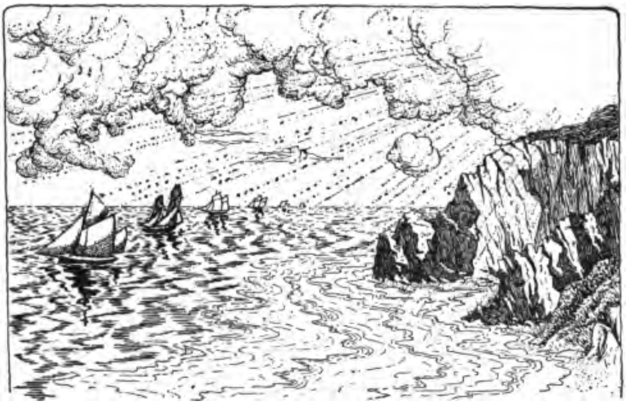


FIG. 97. Why do the vessels in the distance disappear from sight?

time of a lunar eclipse, the appearance of ships as they go out from or come into a harbor on the shore of the ocean, and the experiences of men who have traveled around the earth. Call to mind again the figures given concerning the size of the earth, its diameter, and its circumferences, equatorial and polar. Do not make this review in the house but out of doors. While you are doing this, do not think of your textbook, but rather think of the earth itself.

How soils are formed. Another answer might be made to the question as to what it is you are standing upon. You could reply, "I am standing on the soil," and this answer might suggest questions as to what soil is and where it comes from.

All soils are formed by the breaking down of the solid rock that forms the crust of the earth. This process is going on all the time, now as in ages past. By the freez-

ing and thawing of the water that finds its way into cracks and crevices of rocks; by chemical action of the oxygen of the air; and by the work of water, winds, and plants, the rocks are broken and crumbled into fine particles that we call the soil.

How soils are classified. Soils are classified into three principal types, according to their origin. These are residual soils, or soils that have not been moved from where they were formed; alluvial soils, or soils washed down and deposited by water; and drift, or glacial soils, which have been transported in some cases for many miles by flowing sheets and streams of ice.

Soils formed and deposited by glaciers. From New England to the Missouri River, and from Hudson Bay to the Ohio River, the soil in most places is a bed of loose material consisting chiefly of sand, gravel, small stones, and clay. This material, down to the solid rock, which exists everywhere below the soil, is called the drift. For a proper understanding of the drift, we must again consult geology and there learn the history of the earth through the Glacial Period. As preparatory to this, we may review that part of physical geography which treats of glaciers and the work they are now doing in moving earth and rocks from higher to lower altitudes.

The glacial age. By proofs which cannot be given here, geologists are able to show that at some time before man appeared on the earth, the region that is now the northern part of the United States was covered with a mass of ice, or vast glacier, and not, as it is in this age, with verdure and magnificent forests. This sheet of ice

FIG. 98. Glacial bowlders in a field in Maine.

moved slowly downward from the north, tearing the rocks from their beds and carrying with it, frozen into its substance, all the earth and loose stones lying in its path. By the movement of the glacier, these stones were not only worn and smoothed themselves, but they also helped to break up the rock beneath into clay and sand. Thus in this far-off time we find one explanation of the presence of the rocks and bowlders which cover the greater part of our country north of the Ohio and the Missouri rivers.

The drift. In brief, then, the glacial drift consists of earth and fragments of rocks, more or less finely ground, which were broken off from the solid rock by the great glaciers of the Glacial Period and were brought by that agency from the north to the regions farther south. Some of them were torn from rock beds and ledges

hundreds of miles north of where they now lie, as is shown by the material of which they are composed. Afterwards, when the great glacier melted, there was the further action of running water, the result of which was the spreading of loose material over hills and valleys and the prairie region of our country.

The thickness of the glacial drift has been carefully measured in different parts of the United States and has been found to vary from a few inches to 400 or 500 feet. It is generally thicker in the valleys than on higher land, so that almost all the valleys in the drift regions are more or less filled with drift gravel, sand, or clay.

Exercise 1. If you live in the drift region, ascertain how many wells in your locality go down to the solid rock. In this way you may gain a clear idea of the depth of the drift in the region in which you live.

Alluvial soil. In other parts of the United States, especially on the Atlantic coastal plain from New Jersey southward, on the lowland north of the Gulf of Mexico, and on a wide area along the Mississippi River and its tributaries nearly as far north as St. Louis, the soil is alluvial. Century after century the streams that flow through these and other regions have been washing down soil from the mountains and high parts of the continent and depositing it along their valleys and at their mouths. Alluvial soil can be found along almost any stream, and the soils of many fertile regions, like the valleys of the Nile and of the Ganges, have been transported and laid down in this manner by streams. James D. Dana, the

geologist, says, "The average amount of sediment annually carried to the borders of the Gulf of Mexico by the Mississippi River has been stated to be 812,500,000,000 pounds, or enough to make a pyramid a square mile at the base and over 700 feet in height." The material is deposited about the mouth of the river, and is gradually extending the land farther into the Gulf. The fine sediment of rivers settles much more rapidly in salt water than in fresh, and that is one reason why this material is prevented from being carried off to the deep ocean.

Exercise 2. Hunt for examples of alluvial soil and learn to recognize it as such. In most regions alluvial deposits can be found in the bends of streams.

Residual soils. Most of the people whose homes are in the western part of the United States or in the higher parts of the South live on residual soil. In the process of decay, part of the material of which the rocks are composed is dissolved out of them and carried away, and the soil is composed of those parts of the rock which remain. The character or kind of residual soil depends on the materials of which the original rocks were composed and from which the soil was made. Sandstone and pulverized granite make sandy soils; limestones, feldspar, and shales give clay soils.

Exercise 3. Find examples of rock changing to soil.

An agricultural classification of soil. From an agricultural standpoint, soils are classified as sand, clay, and loam. Sand is composed of rather coarse particles

and clay chiefly of very fine particles, while on the average the particles of loam are finer than sand and coarser than clay.

FIG. 99. Testing the water-holding capacity of soils.

Exercise 4. Press moist sand together in the hand. Do the particles cohere* ? Press an equal amount of clay. Do the particles cohere? Do they adhere* to your hand? Test a loam soil in the same way. A loam soil is more sticky than sand and less sticky than clay.

According to the fineness of the particles of which they are composed, the soils of our country have been classified by the United States Department of Agriculture into more than 400 types, ranging from coarse gravel to very fine clay. Certain crops do well on one kind of soil and other crops flourish on soil of a different type; so to a considerable degree the success of the farmer depends on how well he suits his crops to his land.

The water-holding capacity of soils. Plants take up water through their roots, and one of the important questions about an agricultural soil is the amount of water it will hold. By the following experiment we can determine the water-holding capacity of different soils:

Exercise 5. Take three tin cans of equal size; make a number of fine holes in the bottom of each for drainage. Spread out and dry on papers sand, clay, and loam; fill a

can with soil of each kind. Weigh the cans and their contents, record the weights, and then set the cans in water nearly to the top and let them stand overnight. The next morning take the cans out of the water and, after they have drained thoroughly, reweigh them. Which can has gained most in weight?

The heat-absorbing capacity of soils. Few seeds will germinate at a temperature below 50 degrees, and the roots of many plants do not grow well in a cold soil. Test the heat-absorbing capacity of sand and clay by the following experiment:

Exercise 6. Provide two baking tins. Fill one with moist sand to the depth of 3 inches and the other with moist clay to the same depth. Let them stand in the same room until their temperature, as shown by the thermometer, is the same. Place them on the stove or radiator where they will heat quite slowly. Take the temperature of each soil at equal intervals of time, carrying on the observation while the temperature is increasing and, after the pans have been removed from the fire, until their temperatures are again the same. Tabulate your observations.

Time in Minutes	Clay		Sand	
	Temperature		Temperature	
	Rising	*Falling*	*Rising*	*Falling*

Which soil warms up more rapidly? Which retains its heat longer? Examine again the results you secured in Exercise 5. Do you see any reason for the results you got in Exercise 6? Would a sandy or a clay soil be better for an early spring garden?

Vegetable matter in the soil. If the uppermost layer of the soil be examined, it will be seen that it is of darker color than the soil below and evidently contains something besides mere particles of rocks. Go to some railroad cut or "sand bank" and observe this fact. The color is darkest and the depth of the soil is greatest in places where most vegetable material has decayed; as, for example, in forests where leaves accumulate and decay from year to year, or where grasses or mosses grow luxuriantly and decay, as in marshes and swamps. Notice also that the lightest-colored soil is found in places where the least vegetation has decayed — on dry knolls and in situations where the bed rock comes near the surface. We may thus conclude from our observations that the soil is made darker by the decayed vegetable matter in it.

Humus. This decayed vegetable matter in the soil is known as humus, or mold. An adequate supply of humus is of the greatest importance in agricultural lands, and whenever possible vegetable matter should be returned to the land. Not only does the decaying humus provide plants with certain food elements that they need, but it also makes a soil lighter and looser and greatly increases its water-holding capacity. In reality, the humus in a soil is as much a part of it as are the rock particles;

and it should be added that a complete definition of soil includes also the water and air and the many forms of lowly life that abound in every handful of earth.[1]

The science of agriculture. You must not think that after reading this brief discussion of soils, you are completely informed concerning the adaptation of the different kinds of soil to the raising of crops. The purpose here is only to enable you to appreciate in a general way the somewhat simple classifications of soils that are used and the technical terms that are applicable in each case. It is to be hoped that in the future you will be able to study the science of agriculture, whether you live in the country or the city; for no more interesting life is possible than that of the intelligent farmer who successfully uses a knowledge of science to bend the forces of nature to his will.

[1] Fill a flower pot with soft, dark earth and mold from the border of the wood, and carry it to the student of entomology, to see if he can name one half of the living forms of this little kingdom of life; or hand it to the botanist, well trained in the lower orders of plants, to see how many of the living forms which these few handfuls of dirt contain he can classify. Present this miniature farm to the chemist and the physicist, and let them puzzle over it. Call in the farmer, and ask him what plants will thrive best in it; or keep the soil warm and moist for a time and have the gardener say of the tiny plants that appear as by magic, which are good and which are bad. Mark what all these experts have said, and call in the orchardist to tell you how to change dead, lifeless, despised earth into fruit; ask the physiologist to explain how sodden earth is transformed into nerve and brain. — ROBERTS.

CHAPTER NINETEEN

THE POTATO

A FURTHER STUDY OF THE SOIL

THE average yield per acre of potatoes throughout the United States is about 100 bushels, but when potatoes are properly grown, yields of 250 or 300 bushels per acre are frequently obtained over large areas. There are many records of more than 500 bushels per acre, and one yield of more than 750 bushels per acre has been reported. How can these large yields be secured?


FIG. 100. A potato plant.

An excursion to the garden and a scientific study of some of the facts to be observed there will not only help us in some measure to answer this question but will also teach additional lessons concerning the soil.

A potato an enlargement of an underground stem. Potatoes grow on underground stems; they are in fact only enlargements of the stem. They are properly called tubers and not roots. Pull up a hill of young potatoes and find what appear to be two sets of roots. Carefully trace back to the stem, which is above the ground, those that carry the potatoes; notice that they are really branches of the stem and are quite distinct from the real roots.

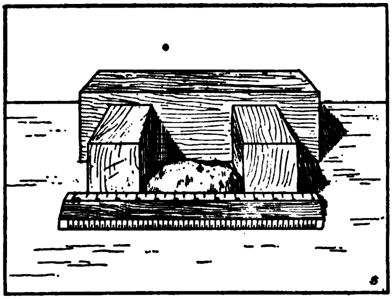


FIG. 101. Measuring the length of a potato.

Exercise 1. Let each pupil bring one or more potatoes from home. Weigh them, one by one; compute the average weight.

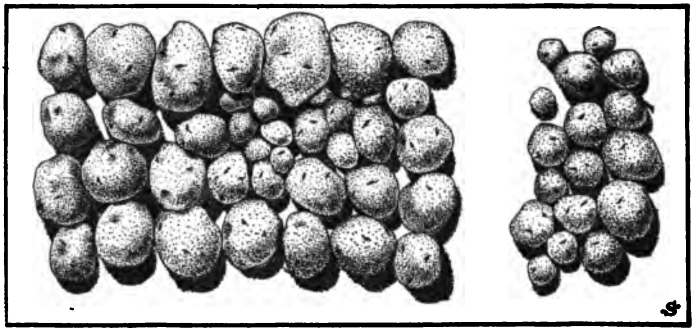
Exercise 2. Measure the potatoes as to length and thickness (Fig. 101); compute the average length and thickness.

The man who deals largely in potatoes will tell you that those ranging from 2 to 3 inches in length and weighing from 5 to 10 ounces are most salable. If smaller than this, they do not cook uniformly, and, when baked or boiled whole, they do not look so appetizing. There is also slightly more waste in paring small potatoes.

Exercise 3. From the potatoes that have been brought to school, sort out those that are most salable.

Selecting seed potatoes. In selecting seed potatoes, dig each hill separately and keep for seed the potatoes from the hill yielding the largest number of the desirable size. Satisfactory results cannot be secured by selecting the best potato from a hill; for a large, smooth specimen may be the only good potato produced in the hill. A plant that has been able to produce but one good-sized potato is not strong enough to bear good seed.

Exercise 4. Have all the potatoes brought in from several hills, selecting low-yielding as well as high-yielding hills. Then repeat Exercises 1 and 2 and find out which hill produced the most potatoes of a desirable size.



From photograph by U. S. Department of Agriculture

FIG. 102. The yield from two hills of potatoes of the same variety, grown in the same kind of soil and under the same conditions.

Would it be better to save seed from a very large watermelon, pumpkin, or tomato that was the only one produced on the plant, or from a moderate-sized one grown on a plant that had produced several others just as good?

A test of quality. A potato should not only be of a certain size; to be of good quality it must also contain a certain percentage of starch.

Exercise 5. Clean a potato thoroughly, dry it and weigh it. Cut it into halves and with a common grater reduce all of it to a fine pulp. Now fold the pulp in a cotton or linen cloth and wash it with considerable clean water, preserving all the wash water. Allow the sediment to settle and then draw off the water and dry the residue. This is pure potato *starch*. Weigh the dry starch and compute its percentage of the whole weight of the potato.

If the percentage of starch falls below a certain standard (about 17 per cent), the reason probably is that the

tubers have not developed properly, have not ripened, or have grown under adverse* climatic or soil conditions. Such potatoes, when prepared for food, will not meet the standard set for table potatoes in this country.

The test for starch. The following experiment shows the method used by the chemist to detect the presence of starch.

Exercise 6. Put some of the starch in boiling water; it forms a paste but does not dissolve. Treat the paste with a few drops of iodin solution formed by dissolving 2 parts of iodin and 5 parts of potassium iodid in 100 parts of water; the starch is colored a dark blue. Add the iodin solution to the surface of a cut potato. A blue color is produced.

The potato is not the only plant that manufactures starch. Test an apple, corn, and other vegetables for starch.

Cooking starchy foods. Raw starch is not easily digested, and hence potatoes and other vegetables and green fruits should be thoroughly cooked. In ripe fruits most of the starch has been changed to sugar, which, because it is readily soluble, is easily digested without cooking. A mealy boiled potato is, in fact, near akin to a lump of sugar; for the potato, like all forms of starchy food, must be turned into a kind of sugar before it can be absorbed into the system.

Color of the potato. Another important thing to notice is the color of the potato. In northern latitudes potatoes with light yellow or whitish skin are preferred, while in many of the southern states the pink-skinned

The Country Gentleman

FIG. 103. **Harvesting potatoes in Maine.**

tubers are liked better. As far as experts have been able to determine, the color of the skin has nothing to do with the eating qualities of the potato.

The texture of the skin. A third point to consider in judging potatoes (what are the two already mentioned?) is whether the tubers have a smooth, clear skin or have one more or less netted. Those of the latter character are usually preferred; for it may be noticed that those which have a smooth or clear skin are apt to be excessively watery and soggy after cooking, while, on the other hand, those with netted appearance or corky touch have a tendency to become mealy upon boiling.

Deep eyes objectionable. Again, potatoes with numerous eyes and with deep eyes are objectionable, because the eyes carry much dirt, and the labor, time, and waste in preparing them for cooking is much greater than is

the case with potatoes of an even surface. The same objections apply to potatoes of irregular shape.

Testing quality with a knife. A crisp, snappy condition of a potato when cut indicates an abundance of starch grains. When the cut is leathery, soft, smooth, and even, it indicates an overgrowth of fiber in the potato and an inadequate supply of starch. In the first case there is sufficient starch to swell the tuber and make it mealy when boiled. In the second case there is not enough starch present to break up the structure, and, in cooking, the tuber retains its form and oftentimes is watery and soggy.

FIG. 104. A soil thermometer.

Conditions necessary to produce good potatoes. If now we seek to know the conditions of growth which will produce good potatoes, we shall find that mealiness, when cooked, and also a good flavor, depend in the main upon three conditions:

First, and most important perhaps, is the daily range of temperature of the air and the soil. Though it cannot be laid down as an absolute rule, it is believed that good quality is developed under a soil temperature of between 65 and 75 degrees F. Let us stop and ascertain what this statement means.

Exercise 7. Hang a thermometer at some point in a potato field, 1 foot from the ground, and take the temperature of the air. Place the bulb of the thermometer upon the surface of the

ground and note the temperature. Thrust it 2 inches into the ground, then 4 inches, 6 inches, and 8 inches, taking the temperature at each depth. Repeat these observations several times, so as to obtain the average temperature for each depth.

Repeat the above observations several times through the season while the crop is growing, recording the results in a table like the following:

TEMPERATURE OF AIR AND SOIL OF POTATO FIELD

Date	Time of Day	Temperature of Air	Temperature of Soil				
			Surface	2 in.	4 in.	6 in.	8 in.

Would a sandy or a clay soil be best for raising early potatoes? Why? In your region, what kind of soil do the farmers consider best adapted to potatoes?

Exercise 8. On a sunny day late in spring take the temperature of the soil on the north side and on the south side of a hill. Results? Is a northern or a southern slope better for early potatoes?

A *second* consideration of great importance in raising potatoes is the depth at which the seed should be planted.

We may study with profit some results obtained at the Agricultural Experiment Station of Cornell University.

TABLE SHOWING THE EFFECTS OF PLANTING POTATOES AT DIFFERENT DEPTHS

Number of hills		85	85	85
Depth planted		2″	4″	6″
Number of tubers		1050	996	913
Weight in kilos[1]		74.867	86.812	113.44
Size of tubers	Large	294	435	496
	Small	756	561	417
Exposed to sun	Number of tubers	514	204	113
	Weight in kilos	28.712	13.617	15.891

[1] A kilo = 2.2 pounds; a bushel of potatoes weighs 60 pounds.

At what depth of planting was the greatest number of potatoes found? At what depth was the greatest weight produced?

Considering the last two questions, what can you say concerning the size of the tubers in each case?

What is meant by the statement that "the number of the potatoes in the hill varies inversely as the depth of planting"?

Is there any good reason why the size of the potatoes should not have been larger if the seed tubers had been planted 8 inches deep? Ought we to take the temperature of the soil into account?

Exercise 9. In each of the three cases above compute the percentage of large and small potatoes; enter the results in a table and state your conclusion. In each case figure out the percentage of exposed potatoes.

The Country Gentleman

FIG. 105. A potato field in the irrigated region of Colorado.

No tubers were found growing deeper than the seed was planted. This teaches us that the time to regulate the depth at which the potatoes are to grow is in planting. Of course, the final depth can also be regulated by the amount of soil which is placed over the hill. When planted shallow, potatoes are more likely to become exposed to the direct rays of the sun, in which case they turn green and are spoiled for food.

In the *third* place, the quality of the potato and the yield per hill depend upon the degree of ripeness of the tubers when the plant dies. Young tubers taken from green and growing plants are better than unripe tubers taken from plants that are dead. The best potatoes are those that ripen fully while the top is still green.

What is the average yield per acre of potatoes in your locality? Ask the farmers.

What have been the ruling prices for potatoes in the market for the past three or four years? Ask the farmer and the grocer.

The best soil for the potato. The potato requires a fertile soil. A rich, sandy loam well supplied with organic matter and well drained is the best, although potatoes may be grown on nearly every class of soil. Very heavy clay is not good and should not be used if the farm affords any lighter soil. Potatoes are often raised on light, sandy soils, but such a soil must be well fertilized.

One year, or at the most two years, is the longest time potatoes should be grown on the same field. This is especially true if there has been a tendency to diseases of any kind. A clean crop cannot be expected from a field which has produced scabby tubers. The germs that cause the scab live in the soil, but they can be starved out by growing other crops on the land for several years.

In the central part of the United States and elsewhere a rotation* of crops has given very satisfactory results, and large yields of potatoes have been secured. The rotation may be: fall wheat, in which clover is sown in spring; second year, clover plowed under in the fall or winter; and the third year, potatoes.

The lesson to be learned. You must not think that the object of this chapter is merely to teach facts concerning the growth and culture of the potato. It is intended to do this, it is true; but the primary object of this study is to show how, by careful observation and study of facts, conclusions may be reached and out of

these conclusions there may be developed a method by which the largest and most profitable crops may be produced from the soil. You are to see how your scientific method may be employed in this and similar cases to raise farming from mere drudgery to an intensely interesting scientific pursuit.

CHAPTER TWENTY

A STUDY OF THE AIR

NUMEROUS animals, as the mole and the earthworm, spend their whole existence underground. Some of them will seek the surface occasionally, in a storm or in the darkness of night; but when they do this, they are away from their natural home and are blind to the beauties and advantages of life above ground.

Other animals live in the water that covers the greater part of the earth. Some of them, as the whale and the porpoise, come to the surface of the water only to breathe; others, like the minnow, the shark, the carp, and the eel, sometimes break the surface of the water to take food that is floating there; but many animals know no life except one that is lived far beneath the surface of the water.

Plants occupy two different zones; they lead a double life. The roots of the clover, the corn, the grape, the pine, and the palm lead a busy life beneath the soil. The tops push up to a freer existence in the air.

Man lives upon the surface of the earth. He is fitted to live in the air. As the deep-sea animals live at the bottom of an ocean of water, so man spends his existence at the bottom of an ocean of air. This air, or atmosphere, is of the greatest interest to us all. It is the subject of our study in this chapter.

The air a material substance. First of all we should prove to our satisfaction that the air is really a material substance. Review the experiments described on page 29.

Exercise 1. Move your hand quickly back and forth and convince yourself that there is an invisible something all about you. Use a fan in order to prove the presence of the air more plainly.

Exercise 2. Stand out of doors in the wind and consider what it is that meets you in the face and disarranges your hair and clothing.

The chemical composition of air. Figure 107 shows a bell jar, or, as it is commonly called, a receiver, open at the bottom. An old bottle with the bottom cracked off may be used instead, in the following interesting experiment:

Exercise 3. Carefully dry a small piece of phosphorus no larger than a small pea by pressing it between folds of blotting paper.[1] Place it on a cork floating on the water in a basin. Light the phosphorus with a hot wire and quickly set the bell jar over it.

Caution! Take great care in handling phosphorus. Keep it under

FIG. 106. We live at the bottom of an ocean of air.

[1] The essential features of this experiment may be shown by lighting a piece of paper, throwing it upon the surface of some water, and holding a tumbler over it.

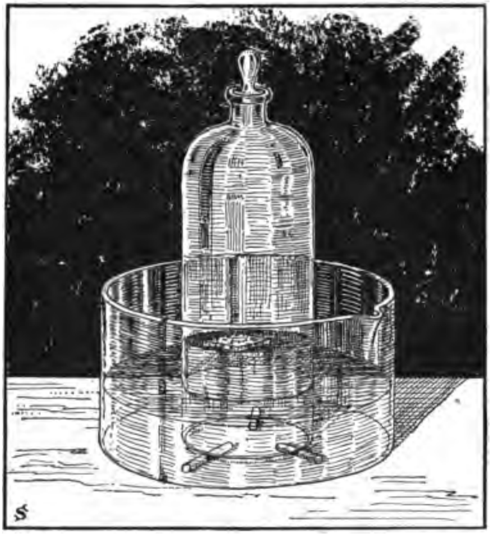


FIG. 107. When the phosphorus burns the water rises in the bell jar.

water when not using it and never touch it with your fingers, as it may adhere to the skin and burn you severely.

What chemical action is going on while the phosphorus burns? Why does it cease to burn? What is the chemical name of the white compound which composes the fumes (page 95)? its chemical composition?

Let the jar stand for some time. The white fumes will dissolve as they fall into the water. Notice that at the same time the water has risen about one fifth of the way up the jar. This fact will lead to an important conclusion a little later.

Is the gas which remains in the receiver the same as the air which we first inclosed in the bell jar? This is a question that should be answered with great care. The next exercise will give you the answer.

Exercise 4. Light a pine stick. Will it continue to burn as long as you leave it in the open air? Take the stopper from the bell jar and plunge the lighted stick into the gas in the jar. The flame suddenly goes out. Repeat the experi-

ment. Try the same experiment in a bottle or receiver containing ordinary air.

We have here come face to face with some facts concerning the chemical constituents of the air:

(1) There is something in the air which has united with the phosphorus and burned it. In that chemical action both the phosphorus and the something disappeared and water rose in the jar and took its place.

(2) There was something in the air which did not unite with the phosphorus and that something remained in the jar. How do you know there was something in the jar after the phosphorus was burned? We conclude that the air is made up of at least two substances.

Nitrogen and oxygen in the air. The gas that remained in the jar is nitrogen. It is one of the two principal gases which go to make up the air. About what proportion, by volume, of the atmosphere is nitrogen? Something that happened in Exercise 3 should enable you to answer this question. Nitrogen is a non-supporter of combustion, as you proved in the last experiment.

The gas which has been removed from the air in the jar is oxygen. As we learned in Chapter Six, oxygen aids or supports combustion, or burning. Review the experiment with the iron picture cord and oxygen as given on page 48. Is not the advantage of having the air composed in part of nitrogen very evident? If the air consisted entirely of oxygen, all things would burn very much more rapidly than they now do. In fact, not only would the coal or wood burn in the stove, but the stove itself would burn.

Both oxygen and nitrogen are transparent, colorless, tasteless, and odorless gases. How do you know this? Are your nose and mouth full of air at this moment?

The proportions of oxygen and nitrogen in the air. The exact proportions of oxygen and nitrogen in air that has been freed from water vapor, carbon dioxid, and other substances is:

	BY VOLUME	BY WEIGHT
Oxygen	20.9%	23.1%
Nitrogen (including argon)	79.1	76.9
	100%	100%

Nitrogen an inactive element. Nitrogen is, in its chemical nature, extremely inactive; that is, it does not readily unite with other elements. For example, it has been mixed with the oxygen in the air during all the thousands of years that have passed since the atmosphere of the earth was formed; and yet, in spite of the intense activity of oxygen, the nitrogen and oxygen are only mixed in the atmosphere,—they are not chemically combined. A lightning stroke will compel them to unite, forming a very small amount of nitric acid (HNO_3); but in the air it is only in this very unusual way that the union is brought about.

Nitrogen compounds not plentiful. In view of the facts stated in the last paragraph, we are prepared to learn that compounds of nitrogen are not very plentiful. They are found in any considerable amount in only a few places, and these places are, for the most part, not in the United States. Near the boundary between Chile and Peru are found great beds of Chile saltpeter, or

From photographs furnished by Pan-American Union

FIGS. 108 and 109. Views in the sodium nitrate fields of Chile.

sodium nitrate ($NaNO_3$), and for years past many of the nations of the earth have been going to that region for their nitrogen supply.

Our lives dependent upon compounds of nitrogen. Every living plant and animal is built partly of nitrogen, and the continuance of the life of all living things depends on their being able to procure compounds of nitrogen for food. Over every acre of ground there are thousands of tons of nitrogen, but animals and ordinary plants cannot use it in this free, or uncombined, form. The nerves, muscles, and glands of our bodies are compounds of nitrogen, and we must have compounds of nitrogen in our food. Plants likewise must have nitrogen compounds which they get from the soil. In ordinary soil only a small supply of nitrogen compounds is present, and one of the great problems in agriculture is to keep sufficient nitrogen in the land.

Help from the legumes. What shall be used for fuel when the beds of coal are all gone is an important ques-

tion. It is likewise a question of vital importance how the people of the world can be supplied with nitrogen compounds when the South American deposits that we are now using shall have been exhausted. In our difficulties we often get relief from unexpected quarters, and in this case it seems that we shall be saved from a nitrogen famine by the legumes,* a certain family of plants. This family includes the clovers, alfalfa, peas, beans, and the vetches. Unlike other plants, these plants do not use what nitrogen they find in the soil and then leave the soil much poorer in that material; they have means by which they draw nitrogen from the air and make compounds of it for their use.

Exercise 5. Pull up a clover or alfalfa plant and notice on its roots numerous small swellings, called *tubercles*. If you were to crush one of these tubercles and examine it with a powerful microscope, you would find thousands of tiny, living bacteria* growing in it.

FIG. 110. Tubercles on the roots of a clover plant.

The secret of the clover plant. The bacteria in the tubercles take nitrogen from the air and combine it with other elements that will make food for the plants. Notice that it is not the clover plant itself that possesses this power. This very important work, so necessary to all mankind, is done by these smallest of living plants, the

FIGS. 111 and 112. When the leaves are burned the nitrogen escapes into the air. But when they are buried the nitrogen in them is returned to the soil.

bacteria. The clover gives them a place to live in and do their work. Then it absorbs the compounds produced by the bacteria into its roots and uses them in its growth.

So you can now understand how it is that the clover plant not only provides its own nitrogenous food, but, if it is plowed into the soil or if its roots decay in the ground, leaves in the soil a large amount of such food for other plants. The leguminous* plants also contain the nitrogen compounds that are necessary to animals, and they are eaten by the ox and other herbivorous* animals. These in turn are used as food by man, so you must thank the clover plant or some of its relatives and the little bacteria that are partners in the work, both for the meat that you eat and the bread that the nitrogen enables the wheat plant to furnish you.

"Sweetening" acid soil. Bacteria that have the power to fix or combine nitrogen cannot live in an acid soil,

and clover and alfalfa will not flourish in such soil until the acid has been neutralized. Slaked lime and finely ground limestone are much used for this purpose. Limestone can often be found in the form of finely divided marl in the bottoms and along the shores of freshwater lakes, and this marl may be used to sweeten acid soil.

Keeping up a supply of soil nitrogen. It should be remembered that all decaying vegetables, plants, leaves, and barnyard manure contain compounds of nitrogen. They should be returned to the soil so that other plants can make use of the nitrogen. It is wrong for the gardener to burn the leaves that fall from the trees, for when this is done the nitrogen returns to the air in the free state. For the same reason the farmer should return to the soil every form of decaying vegetable life, — the manure from the barnyard, straw, cornstalks, and green plants.

Commercial fertilizers. Combined nitrogen can be bought in the form of ammonium sulfate [$(NH_4)_2SO_4$], sodium nitrate ($NaNO_3$), or potassium nitrate (KNO_3). These are mixed with the other elements which also are necessary to the growth of plants and are sold as commercial fertilizers. The two elements besides nitrogen that are often lacking in soils are potassium and phosphorus (page 97).

A study of ammonia. One of the most common compounds of nitrogen is ammonia (NH_3). A brief study of this compound may be made as follows:

Exercise 6. Procure a small amount of ammonium chlorid, or sal ammoniac. Examine it carefully. It is a

white crystalline solid, has a sharp, caustic taste, and yields no odor.

Place a small amount of powdered quicklime in the palm of one hand and a like amount of ammonium chlorid in the palm of the other hand. Then rub the two together. Very quickly a strong odor of ammonia is developed. Hold a moist piece of red litmus paper in the gas which is coming from your hands.

FIG. 113. Preparing and collecting ammonia.

Ammonia is a colorless, irrespirable* gas, has a strong odor, and is lighter than air. The ammonia that is sold for household use is made by dissolving the gas in water. As you have learned from your experiments, ammonia is an alkali, and acids may be neutralized by it (page 90). In its gaseous form ammonia is used to produce the cold in ice factories and in cold storage plants (page 259).

A striking experiment. Ammonia is soluble in water to such an extent that 1000 cubic feet of the gas can be dissolved in 1 cubic foot of water. This fact can be made the basis of a most interesting experiment.

Exercise 7. Heat in a flask a mixture of quicklime and ammonium chlorid and collect the ammonia that is given off by downward displacement of air (Fig. 113). Close the bottle with a stopper through which is passed a glass tube, and

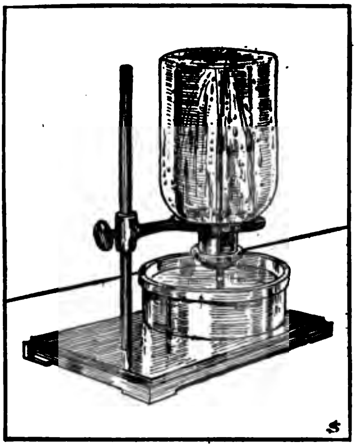


FIG. 114.

then arrange in the manner shown in Figure 114 a vessel of water colored red with litmus. The liquid rushes up into the bottle and turns blue. Explain (1) why the litmus water enters the bottle and (2) why it changes its color. Perhaps you will be able to answer the first of these questions better after your study of the next chapter.

Use of nitrogen compounds in war. Potassium nitrate is used to make gunpowder and other forms of explosives. Guncotton is made by treating cotton with nitric acid, and dynamite also is a nitrogen compound. Nitrogen compounds are used in immense quantities in times of war. By using electricity it is possible to make nitric acid from the nitrogen in the air, and from nitric acid almost any desired nitrogen compound can be made. The United States government is now spending many millions of dollars on a great nitrate plant so that we may have a supply of nitrogen compounds produced within our own borders. Every time a great gun is fired a large amount of nitrogen is set free and is no longer of any use to man.

Other gases in the air. In a former chapter we learned that there is carbon dioxid in the atmosphere (page 109). This is present in very small amounts;

FIG. 115. Why does the water collect on the outside of the pitcher?

there are only about 4 parts of carbon dioxid in 10,000 parts of air. A small quantity of ammonia formed by the decomposition of animal and vegetable matter also exists in the air, and there is a considerably larger amount of argon, a gas which can be detected only by the refined methods of the chemical laboratory. Water vapor is always present in the air, as you can prove by the following experiment:

Exercise 8. Lay a small piece of dry potash (KOH) in an open dish and expose it to the air. Water will be taken up from the air and the potash will be dissolved. This is a proof of the presence of water vapor in the air.

Another proof that the air contains water vapor is found in the fact that drops of water may often be seen upon the outside of a pitcher containing ice water. These drops of water do not soak through the pitcher from the inside. Where do they come from (page 63)? Observe that more water gathers on the pitcher on a warm, humid day than on a clear, cold day. Why?

What is the source of dew? What is frost?

CHAPTER TWENTY-ONE

THE WEATHER

A FURTHER STUDY OF AIR

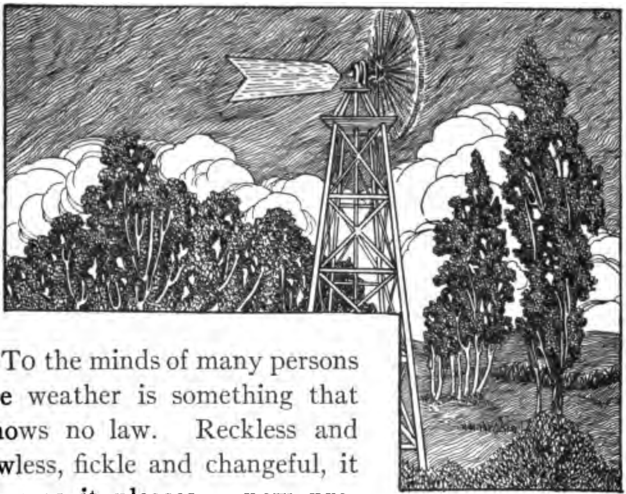


FIG. 116.

To the minds of many persons the weather is something that knows no law. Reckless and lawless, fickle and changeful, it does as it pleases, — now providing a beautiful day for an outing, a football game, a picnic; now turning with vengeance against man and nature, and uprooting forests and destroying life with none to hinder.

There is some reason for this conception of the weather; but we should learn that nature, in all its moods, acts under laws that are uniform and unchanging; that there is a science of the weather that is well known to those who make a study of the subject. Through the very efficient labors of the United States Weather Bureau, maps and bulletins showing weather conditions in all parts of the country are sent out daily.

FIG. 117. An air globe.

What is the weather? By the "weather" are meant the temperature, moisture, pressure, rate of movement, and other conditions of the atmosphere. It has to do with the degree of heat or cold; wetness or dryness; rain or snow; calm or storm; clearness of the sky or cloudiness; gentle breeze or tornado; spring shower or blizzard; flood or drought.

This is an important subject, having to do with our personal comfort, our health, and our success or failure in raising crops and in transporting these products to the markets of the world. Indeed, the weather has its influence upon every movement and every activity of human society, and we should know the common facts about winds and the causes of changes in the weather. The best way to begin our study of the subject is to learn some additional facts about air.

The weight of air. One definition of matter is that it is anything that has weight. Is air matter? Can you weigh it? If the school has the apparatus, you can answer this question by an experiment.

Exercise 1. Open the stopcock of an air globe like that shown in Figure 117 and weigh the globe. Attach an air pump to the globe and force as much air as possible into

it. Now close the stopcock and weigh the globe. It will be found that it has gained in weight. Why?

From this experiment we may conclude that air is matter and that it has weight. A cubic yard of air under ordinary conditions weighs about 2 pounds. What would be the weight of the air in a hall 30 feet square and 12 feet high?

Air and pressure. Another fact that we need to understand is that air exerts pressure on us and on everything about us.

Exercise 2. Bind a piece of thin sheet-rubber over the mouth of a common clay pipe; put the stem of the pipe in your mouth and draw out the air from the bowl. What happens and why? Why is not the rubber pressed down when the pipe is full of air?

Exercise 3. Fill a tumbler full of water, cover it with a sheet of writing paper, and invert, holding it at first with the hand without letting water escape or any air get inside the paper. The air exerts a pressure from below on the paper more than sufficient to support the weight of the water. With care the tumbler may be held in different positions, thus proving that the air presses alike in all directions.

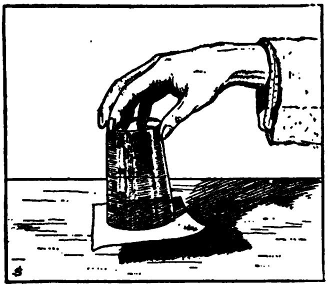


FIG. 118. The upward pressure of the air supports the water in the glass.

We live at the bottom of an ocean of air, and just as there is great pressure from the weight of the water at the bottom of the sea, so is there pressure at

the surface of the earth from the weight of the air above. This pressure at sea level is about 15 pounds to the square inch. Like the pressure in water, air pressure is exerted in all directions, — upward, downward, and laterally.*

How much is the pressure of the air on a square foot? on a square yard? Why does not the pressure of the air crush us?

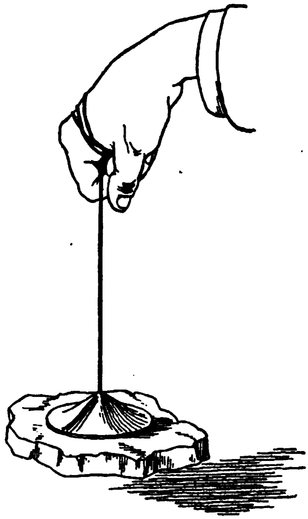


FIG. 119. The pressure of the air holds the sucker against the stone.

Exercise 4. Fasten a string to the center of a round piece of leather. Wet the leather to make it pliable, and press it down evenly on a smooth, flat stone, making sure that there is no air between the leather and the stone. The stone, if not too heavy, can be lifted by the string; the pressure of the air holds the leather to the stone. Measure the area of the leather and compute the air pressure upon it at the rate of 15 pounds to the square inch. How does that pressure compare with the weight of the stone? An ordinary plate may be used for the experiment, instead of the stone.

If the school possesses an air pump and a pair of Magdeburg hemispheres, an experiment can be made that shows in a very striking way the pressure of the air. This experiment was first done 300 years ago by Otto von Guericke, a scientist and the burgomaster of Magde-

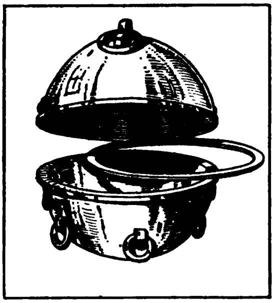


FIG. 120. The Magdeburg hemispheres used by Otto von Guericke in his famous experiment. The opening through which the air was exhausted is in the bottom of the lower hemisphere and is not shown in the illustration.

burg. The apparatus needed consists of two brass hemispheres (Fig. 120) which fit each other so as to be perfectly air tight. When the air is drawn out, removing the inside pressure, a very great force is required to pull them apart.

The hemispheres used by Guericke are in the museum at Berlin, and with them is a Latin book which contains an account of his experiment. His hemispheres had a diameter of about twenty inches, and after the air was thoroughly exhausted he hitched horses to each hemisphere in a great tug of war. He put eight horses on a side before the spheres could be pulled apart. How many horses would he have required if he had hitched one of the hemispheres to a tree?

Measuring the pressure of the air. The pressure of the air is measured by an instrument called the barometer. The principle involved in its use may be understood from the following experiment:

Exercise 5. Completely fill with mercury a glass tube about 32 inches long, closed at one end and open at the other. Place your thumb over the open end. Then invert the tube and place the open end in a dish of mercury. Immediately the mercury falls to about 30 inches, measured from the surface of the mercury in the dish.

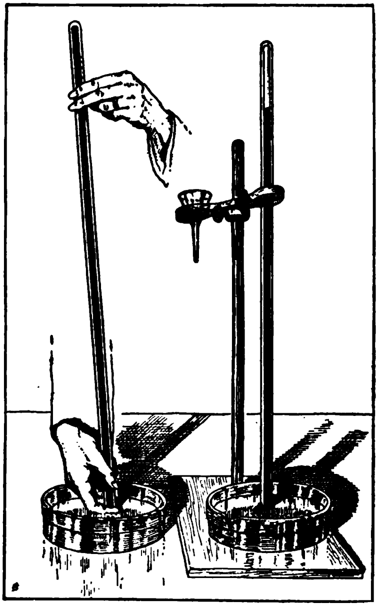


FIG. 121. Setting up a barometer.

What holds the mercury up in the tube? It is the pressure of the air on the surface of the mercury in the dish. Is it not clear, then, that the height of the mercury in the tube will change as the weight of the atmosphere outside changes? The more heavily the atmosphere presses on the surface of the mercury in the dish, the higher it will force the column of mercury in the tube; and if the air becomes lighter and presses with less force on the mercury in the dish, the mercury in the tube will fall. Therefore we may expect the barometer to show any changes in air pressure as they occur.

If you should carry a barometer to the top of a high mountain, would the mercury in the tube rise or fall? Why?

Exercise 6. Set up in the schoolroom the barometer which you made in the last exercise. Does the column of mercury rise and fall from day to day? Why?

A barometer is an instrument for measuring the pressure of the atmosphere. The law of the barometer is:

the heavier the air, the higher the column of mercury; the lighter the air, the lower the mercury.

Storms. The word "storm" is a very general term used to indicate a more or less violent disturbance of the atmosphere, which is characterized by high winds and is accompanied usually, but not necessarily, by some form of precipitation, as rain, snow, hail, or sleet. Storms are often attended by electrical phenomena* and are then classed as thunderstorms. Storms are sometimes named with reference to some phenomenon that attends them; thus we have rainstorms, hailstorms, snowstorms, sandstorms, cyclonic* storms, so called after the whirling motion of the wind. There is also a very destructive whirling local storm known as a tornadic storm, or simply a tornado.* Tornadoes are not of wide distribution and occur only infrequently. In our country they are most common in the Mississippi Valley states during the spring months.

Force exerted by winds. Ordinarily the air is soft and offers little resistance to our passage through it. We hardly feel it when we are walking; but if we run we notice it, and if we go rapidly against it, as on a bicycle or in an automobile, we find its pressure quite strong. Whenever a storm arises and the air moves with great velocity, it exerts a tremendous force. Speaking in terms of the molecules of the air, what is happening to you when the wind blows against you?

Exercise 7. Watch a windmill and estimate in a general way the power and force of the wind when it is in motion. Find out, by inquiry, or from books, how much water a wind-

mill will pump and what horse power it develops in a moderate wind. The Encyclopædia Britannica will give you information on this subject.

Force and name of winds. The wind scale given below is in general use throughout the world to indicate the force of the wind when instrumental measures are not available. This scale was proposed by the late Admiral Beaufort, of the United States Navy, and is popularly known as Beaufort's Scale.

BEAUFORT'S SCALE, USED IN PREPARATION OF ALL WEATHER BUREAU WIND FORECASTS AND STORM WARNINGS

FORCE	DESIGNATION	MILES PER HOUR
0	Calm	From 0 to 3
1	Light air	Over 3 to 8
2	Light breeze (or wind)	Over 8 to 13
3	Gentle breeze (or wind)	Over 13 to 18
4	Moderate breeze (or wind)	Over 18 to 23
5	Fresh breeze (or wind)	Over 23 to 28
6	Strong breeze (or wind)	Over 28 to 34
7	Moderate gale	Over 34 to 40
8	Fresh gale	Over 40 to 48
9	Strong gale	Over 48 to 56
10	Whole gale	Over 56 to 65
11	Storm	Over 65 to 75
12	Hurricane	Over 75

About how many miles an hour will a man or a horse walk? How fast will a freight train move? a fast express train? a steamship? an aëroplane? a bird?

A storm on a small scale. It will be an easy task to produce in the schoolroom a model of a cyclonic storm in

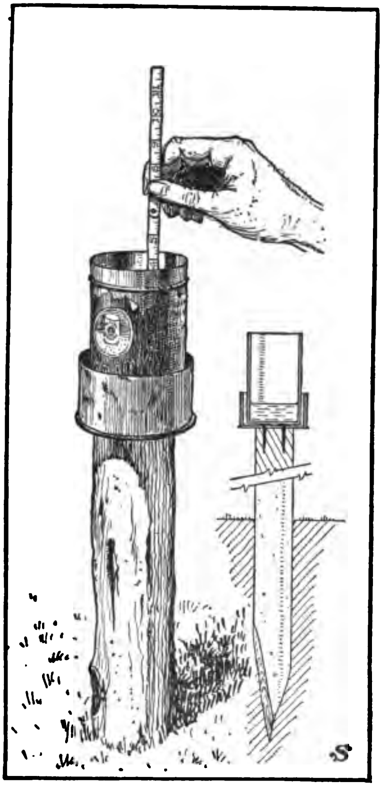


FIG. 122. A rain gauge.

which we may observe some of the essential features of the great storms that sweep over the earth. A stub of candle an inch or so high, a lamp chimney, and a bit of smoke paper will furnish the required apparatus.

Exercise 8. Light the candle and with a drop of the melted wax anchor it to the table. Place the chimney over the flame and raise it a short distance above the table by placing small pieces of a match under it. Hold the smoking paper in the air above the chimney and observe the ascending column of air. How high does the air rise? Be careful not to produce any air currents by your own movements. Let the candle do it all. What finally becomes of the air that rises?

Observe the currents of air entering at the bottom of the chimney. Do they come from one direction or all directions? Move away from the chimney and see how far

away you can detect the air currents setting in towards the heated column.

The "storm," as we have produced it, thus far consists of: (1) a column of heated air rising upward over the heated area, with (2) currents of air passing into this heated area from all directions.

Exercise 9. Carefully remove the lamp chimney and test with the smoke paper as before. The heated area will tend to spread out and the storm will cover a larger area. Some of our storms cover an area several hundred miles or even a thousand miles in diameter.

Why air rises. Why does the heated air rise from the candle?

Exercise 10. Set a glass bulb with a long stem in a vessel of water. A bottle with a stopper arranged as shown in Figure 124 may be used. Lay the hand on the bulb or heat it with a lamp. What emerges* from the mouth of the tube? Is there now as much air in the bulb as there was when the air was cold? Has the air in the bulb lost in weight?

FIG. 123. When the bulb is heated the air within it expands.

When air is heated it expands, and a cubic foot or a cubic yard of such air is lighter than a cubic foot or a cubic yard of cold air. It therefore rises, and the cold,

FIG. 124.

heavier air flows in from the sides to take its place. When the sun shines hot on an area of land, — as it does, for example, on India or the southwestern part of the United States during the summer months, — the air over such a region expands and becomes lighter. This causes it to rise, and the winds move in toward the heated area from all directions. An area of light and rising air of this kind is a storm center.

Cyclones or cyclonic storms. There is a very important fact about cyclonic storms that cannot be shown in the experiment with the candle. Because of the rotation of the earth on its axis, a force arises which tends to deflect* to the right all motions in the northern hemisphere. Consequently the winds flowing toward the storm center are deflected, or turned, to the right and thus move spirally around the storm center, as shown in Figure 125. The term "cyclone" has been applied to this system of whirling winds around a central region of low pressure, and almost all storms have this peculiar cyclonic movement. In the tropics these motions are often so intense that they carry destruction and devastation in their path; but in the majority of cases in extra-

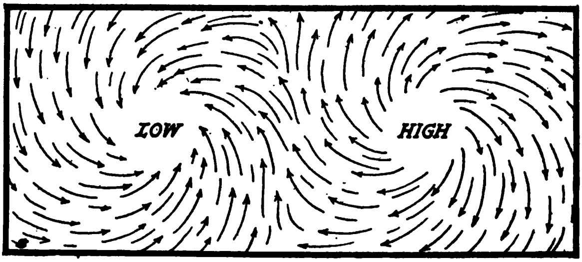


Fig. 125. Diagram to show general directions of winds near the surface of the earth in a cyclone and anticyclone in the northern hemisphere.

tropical latitudes they are not severe. Note that in the center of a cyclone there is a region of low barometric pressure.

Anticyclones. In general, for every extra-tropical cyclone there is a corresponding anticyclone. The air which rises over a storm center cannot get very far above the earth because it is being pulled back to the earth by the force of gravity. This may occur many miles away from the storm center; and because the air is piled up in certain regions the barometric pressure is increased. In other words, the anticyclone is an area of high barometer, and the circulation in an anticyclone is directly opposite to that in a cyclone. In a cyclone the lower air moves spirally toward the storm center, rises, and flows off laterally at the top of the column of ascending air. In the anticyclone the upper air moves toward the center, descends, and flows off spirally along the surface of the earth. In winter, areas of high pressure often form over the mountains of western Canada, and from there the cold, heavy air slides down as blizzards

across the Dakotas and other states lying to the east and south.

On the weather map the storm center is indicated by the word " low " and the anticyclone, or area of clear weather, is marked " high."

The movement of storms. Another fact about cyclonic storms should be noted. The storm as a whole has a progressive motion which is entirely distinct and separate from those already described. It usually moves in an easterly or north of easterly direction, at a rate of from 300 to 500 miles a day. A large number of our storms begin in the Canadian Northwest, and these may cross the Great Lakes and appear a day or so later over the Eastern states.

The cause of this onward passage of a storm across the country is not yet clearly understood, but it seems to be intimately associated with the general circulation of the atmosphere and probably derives its energy from the same source as the latter.

Rain or snow at the storm center. Another fact connected with a storm may now be understood. The air that moves into the heated area is more or less saturated with water vapor, and as this moisture-laden air ascends into the colder air above, the vapor becomes condensed into water and falls to the earth. Frequently it rains or snows near the storm center.

Because of these two reasons the storm center is the area of low barometer.

The barometer and the storm center. There are two reasons why the pressure of the air at the center of a

cyclonic storm is less than that of the air surrounding it:

(1) In the beginning, at least, the storm center is a heated area, and the air there is lighter than the air which surrounds it.

(2) The air is ascending and therefore the pressure below it must decrease.

What will the weather be tomorrow? The barometer will help us to answer this question, but we must understand that the mere height of the mercury in the barometer tells us little or nothing about the weather. It is a careful study of the changes, or ups and downs of the barometer, that will enable us to judge what the corresponding changes in the weather will be. General conclusions may be drawn from three possible conditions:

(1) A rising barometer generally precedes fair weather.

(2) A falling barometer usually precedes stormy or bad weather.

(3) A steady or stationary barometer usually indicates settled weather.

How the weather is studied. If now we bear in mind the fact that what we call the weather depends very largely upon changes of pressure and temperature in the atmosphere, we shall understand how the barometer and the thermometer are used in forecasting the weather. This is the work of the Weather Bureau, which is attached to the United States Department of Agriculture at Washington.

The Weather Bureau. The United States Weather Bureau was organized for the purpose of giving warning to sailors on the high seas or the Great Lakes of approaching dangerous storms, and to farmers and others of threatening rains, floods, cold waves, or destructive frosts. Hundreds of thousands of dollars are saved every year by these warnings. In several hundred localities distributed over the whole country are stationed observers who take observations at the same actual time of day and telegraph their reports to Washington. These reports cover temperature, barometric pressure, the percentage of moisture in the atmosphere, direction of wind, and whether it is clear or cloudy or raining or snowing. The facts thus reported are entered upon a map, copies of which are reproduced on a small scale and sent to a great many post offices and telephone exchanges in the country and published in many of our daily papers.

Exercise 11. Get from the Weather Bureau office in your city or from the Weather Bureau at Washington the weather reports for several consecutive days and make a study of them. On these maps lines are drawn through all places having the same barometric pressure. These lines are called isobars.* Other lines which pass through the places having the same temperature are called isotherms.*

A study of the weather. Study the weather yourself and make notes of what you observe. Watch the changes in temperature, direction of the wind, kinds of clouds, rain, or snow; and, if you have a chance to observe a barometer, see how it changes as the areas of low and high barometer pass over your locality.

A review of what has been learned about storms may be made by the aid of the maps which follow.

Figures 126–128 show the air pressure, temperature, and winds, over the United States on three successive days. The solid lines are isobars, showing differences in air pressure of one tenth of an inch, — the lower the figure, the less the air pressure (29 inches representing a lower pressure than 29.8 inches).

By reference to the three maps which are given here you will be able to answer the following questions for each of the three days:

Exercise 11. How does the temperature vary in the different states? Where were the high-pressure areas? In what direction was the wind blowing in these areas? Where were the areas of low pressure? the storm centers? How was the wind blowing in these areas?

Exercise 12. In Figure 126 a storm is central over northern Texas. How far has the storm, the area of low pressure, progressed by the end of 24 hours? Over what states has it passed? Through how many miles? At what rate per hour? In what direction has it gone? Where was it the day following this? When did it reach the Atlantic seaboard? Where?

Direction of the wind in a storm and after the storm passes. Notice that the wind is blowing from all directions toward the storm center. With this in mind you can understand why it is that the wind changes to the opposite direction when the storm passes over. When the wind changes, of what do you take it to be a sign?

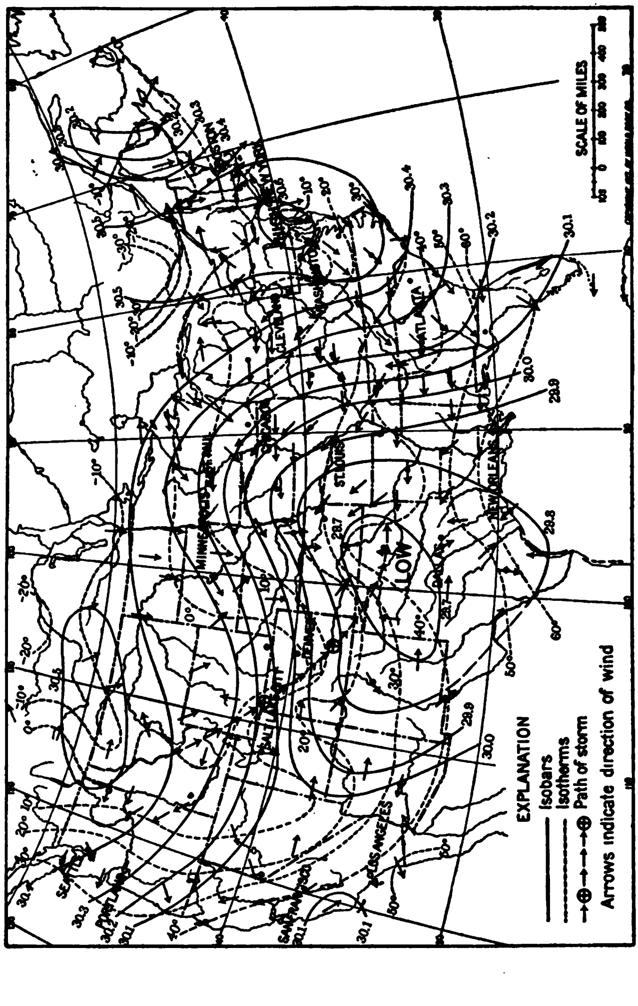


FIG. 126. Weather map of the United States, 8 A.M., January 31, 1908. The previous day the area of low pressure, which is now central over northern Texas, was a short distance east of Salt Lake City.

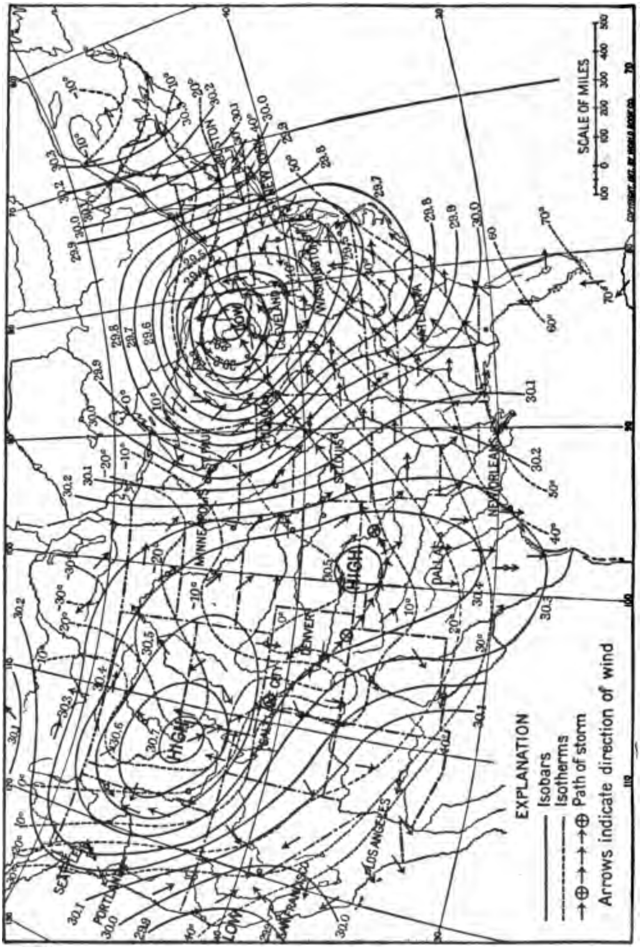


Fig. 127. Weather map of the United States, 8 A.M., February 1, 1908. How many miles has the cyclone traveled in the last twenty-four hours?

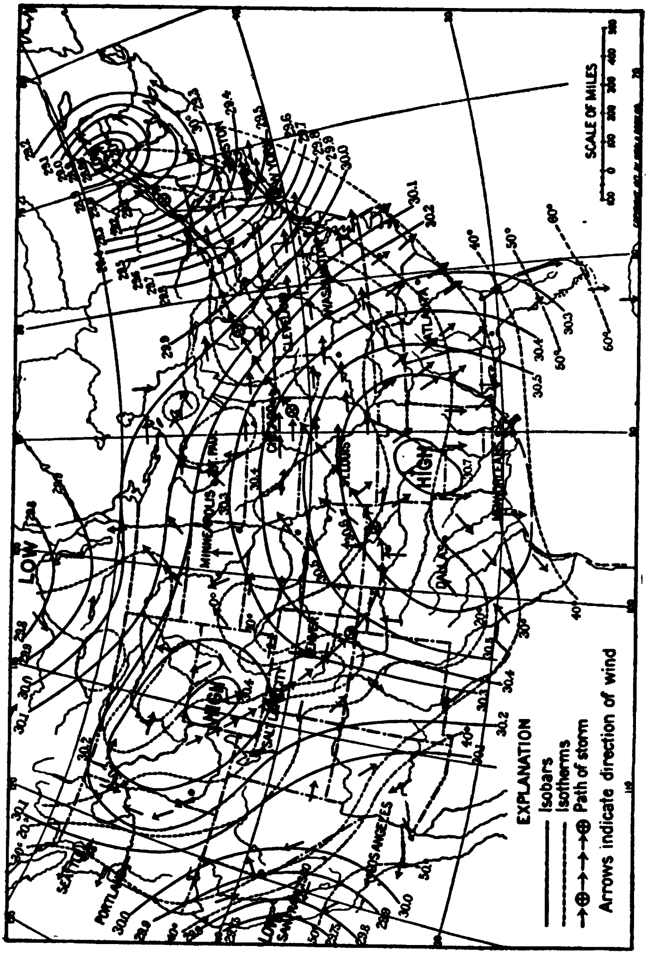


FIG. 128. Weather map of the United States, 8 A.M., February 2, 1908.

CHAPTER TWENTY-TWO

MATTER AND MOTION

In the early chapters of this book you studied the subject of matter. You learned that matter is anything that occupies space, that possesses form, dimensions,* and, especially, weight. You learned some of the properties of matter, — malleability, ductility, hardness, indestructibility, and so forth.

Exercise 1. Make a careful review of Chapters Three, Four, and Five.

In these chapters you learned to make a distinction between matter and non-matter, between the material and the immaterial. The word "matter" has grown in your mind until it has come to include all the objects that your eyes can see or that your other senses can bring to your attention, — the animals and plants that live upon the earth's surface, the water that covers so large a part of that surface, the air or atmosphere that surrounds it, the clouds that float in the sky, and the sun, moon, and stars of the solar system. This is the material world, the universe of matter. Of matter you have asked, what is it? You have studied matter by the method of experiment.

Motion. There are other facts of importance about matter still to be learned. Perhaps you have not thought of it, but the world in which we live is most wonderful, in the fact that everything in it is in constant motion. The rivers flow to the sea; the winds move over the surface of the earth; the waters of the ocean are stirred by currents and tides; and waves of motion are sent through the solid crust of the earth itself by every moving

train or wagon and by every blow from the feet of animals or men. Even when we sit quietly in a comfortable chair at home we are not at rest, but are rapidly moving through space; for the earth is turning on its axis and by this motion is carrying everything upon it through a distance equal to its circumference every 24 hours, while at the same time, with still greater velocity, it is rushing onward in its long journey around the sun. Strange, is it not, that this is so quietly done and at such a uniform rate that nothing on the earth is disturbed and we do not realize that we are in rapid motion!

FIG. 129. Matter is powerless to move itself. A house erected a hundred years ago may be found still standing in the same place.

Some questions to be answered. What is the proof that the earth does rotate* on its axis? Go out of doors at night for your answer. Why do the sun and the moon seem to rise in the east and set in the west? How long a journey do we take every day because of the rotation of the earth? How far do we travel every hour? every minute? Have you ever traveled a thousand miles by train or boat? How long does it take to travel a thousand miles by an express train? Ask the agent at the railroad station for a folder of one of the great trunk lines and find the answer to this question.

Why does the moon rise about 50 minutes later every night? At what time of day do you first see the new moon? Where? When do you first see the full moon? Where? Go to the library and find out how long a trip the earth makes about the sun and how much time it takes to make a complete revolution.*

Even after answering these questions you have not considered all the movements of the earth; for the earth and the other planets (do you know their names?) are all following the sun, "while the sun with his whole retinue* flies with incredible velocity through space."

Matter unable to move itself. Matter is inert,* inactive, powerless to move itself. By itself it is quite helpless to change its position, to move about. Of this fact you can find many illustrations.

A rock lying in a meadow cannot move itself. A tree blown down in a forest by a hurricane lies where it falls. A house or barn erected possibly a hundred years ago may be found still standing in the same place.

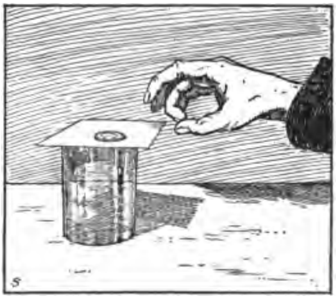


FIG. 130. Why does not the coin move with the card?

Objects like these will never move by their own power. Of all matter we must say that matter at rest will remain at rest until acted upon by some force outside itself. This is true of all forms of mat-

ter; the earth, air, water, rocks, and even machines like automobiles and aëroplanes will lie still and helpless

FIG. 131. Matter has no power to stop itself. A body in motion will remain in motion until stopped by an outside force.

forever unless they are pushed or pulled into motion by some outside force.

Exercise 2. Balance a card on the ball of your finger, and place a coin upon the card. With the finger of the other hand snap the edge of the card quickly. After a few trials you will be able to snap the card away and leave the coin lying on your finger.

You have exerted a greater force upon the card than upon the coin. Consequently the card moves while the coin remains at rest.

Exercise 3. Vary the method of making the last experiment by laying the card upon the top of a small tumbler. The coin will fall into the tumbler.

Moving bodies cannot stop themselves. As matter has not the power to set itself in motion, so matter has no power of itself to stop when once it is set in motion.

FIG. 132. The momentum, or striking force, of the hammer drives the nail into the wood.

It will go on moving forever unless acted upon by some opposing force. For example, take a stone that is set rolling down hill. It is quite plain that it possesses no power of its own to stop in its mad rush down the hill. A train that is running at great speed tends to fly onward, and it can be brought to a stop only by applying great force to the brakes for a considerable time. When an iceberg is sighted in front of an ocean liner the engines are at once reversed, but the ship continues on its course for a time in spite of the action of the engines. A person falling through the air is in a position to understand this helplessness of matter to stop itself. He cannot do anything to check the motion of his body, for he is in the grasp of forces outside himself.

Exercise 4. Draw a line upon the earth and run across it as rapidly as possible. As soon as you cross the line, stop running. Do you have a tendency to keep moving?

Why is a train hard to start but easy to keep moving after it is started?

What happens to a person who is standing in a moving train or street car which is suddenly stopped?

Momentum. By "momentum" is meant the quantity of motion, or, as it is sometimes called, the striking force of a moving body. The momentum of a body equals its mass (the weight) multiplied by its velocity (the rapidity of its motion).

If you have the last statement clear in your mind, you will understand that a small body moving very fast may have the same striking force as a larger body which is moving more slowly. In other words:

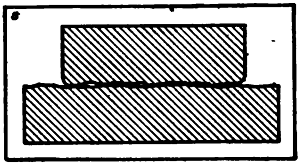


FIG. 133. Diagram illustrating why there is friction when one body moves on another.

The greater the weight the greater the momentum; the less the weight the less the momentum.

The greater the velocity the greater the momentum; the less the velocity the less the momentum.

Illustrations of momentum. A huge iceberg, although moving very slowly, has a tremendous momentum, or striking force, upon a vessel with which it comes into contact.

A large ocean steamship, although moving very slowly, may strike the wharf with great force if the pilot is not careful.

Find an illustration of the fact that a body has more momentum when it is moving rapidly than when it is moving slowly.

Does a heavy body have more or less momentum than a lighter body moving with the same speed? Illustrate.

Can you strike harder with a hammer or with a lead pencil? Why?

Motion destroyed by friction. In spite of the fact that moving bodies cannot stop themselves, objects that we set in motion do come to rest without our help. Why do they not keep moving forever?

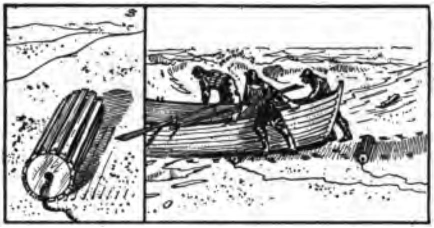


FIG. 134. Rolling friction is less than sliding friction.

Exercise 5. Lay a large book or other heavy object on a desk or on the floor and draw it along. Does something resist the movement of the book? Start the book in motion and let it go. Does it stop?

Exercise 6. Weigh a brick with a spring balance. Tie a string around the brick and with the balance attached to the string draw the brick along the floor. Take the reading of the balance. Explain the difference in the two readings. Does it make any difference whether the brick is laid flatwise or on its edge?

Friction. The resistance which always opposes the movement of one body on another is called friction, and in many cases this is the force which brings moving bodies to a stop. When we roll a ball on the ground, its motion is checked by the friction with the ground. If it is rolled on the sidewalk it will go farther, because there is less friction on the sidewalk than on the rough earth. If it is rolled on the ice it will go still farther, because the ice is very smooth, and there is little friction between the ball and the ice. In all three cases, however, the motion of the ball is being opposed; but if the opposing force could be removed the ball would roll on forever.

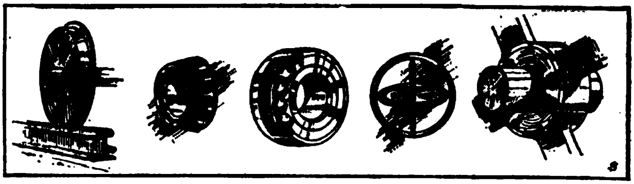


FIG. 135. Some devices to lessen friction.

Friction useful. While friction always opposes motion and results in loss of motion, it should be noticed that in many cases friction is very useful to us. Standing upon the ground or the floor is only possible because of the friction between our feet and the ground. Without friction we could neither walk nor run. Without friction we could not turn a door knob and would have the greatest difficulty in holding anything in our hands; nails and screws would hold nothing together; a locomotive could not start a train.

Practical questions. Is there less friction when a body is dragged or when it is rolled along the ground? Of what use are the wheels on a wagon? Why do we oil the bearings of our bicycles? Why does a ball-bearing lawn mower run more easily than one without ball bearings? Why is a racing automobile made pointed at the front end?

A moving body tends to travel in a straight line. A third fact about matter in motion is that a body in motion will keep moving in a straight line unless acted upon by some outside force.

Exercise 7. Run along the side of the house as rapidly as possible, turn the corner, and continue running along the

wall of the house. Do you have a tendency to keep going in the same direction instead of turning round the corner?

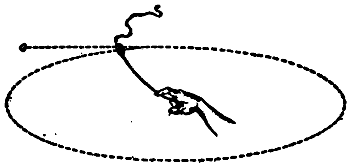


FIG. 136. A moving body tends to travel in a straight line.

Why is a boy who is standing still able to dodge another boy who is running rapidly at him? Why must a trolley car run more slowly when it approaches a sharp curve?

Exercise 8. Make a sling like the one shown in Figure 136. Select a safe place for your experiment, then fit a stone into the sling, whirl it about your head, and release one of the strings. Does the stone continue to move in a circle, or does it travel off in a straight line when it leaves the sling? Why?

Force the cause of motion. What is it that sets objects in motion? How can their motion be stopped or its direction changed? These are questions that we must answer before we can understand many of the things we see and do every hour.

You may change the position of a book on your table by a push or a pull. In either case you have exerted a force upon the book.[1] If the book is very heavy, the force may not be sufficient to cause motion, but we can

[1] A force is a push or a pull exerted by one body of matter upon another body.

FIG. 137.

still say that the force tends to produce motion.[1]

Again, the book might be in motion and the force might change the direction of the motion or bring the book to rest. We may therefore say that a force is that which tends to produce or change motion. Let us study a force whose effects are familiar to us all.

The force of gravity. Once upon a time a great philosopher, Sir Isaac Newton, noticed an apple falling from a tree to the earth. His mind was aroused to find a reason for this. When an apple is separated from the twig on which it grows, why does it fall to the earth? What causes this motion? Why does the apple not remain in the air, or move upward away from the earth?

After a long study of these and other questions, Sir Isaac announced that an apple falls to the earth because every particle of matter in the universe has an attraction for every other particle. Think carefully what this means; it is a most astonishing statement. All bodies of matter pull other bodies of matter toward themselves. The earth attracts the apple and it falls;

[1] One little girl when asked the meaning of this sentence replied, "The force tries to produce motion."

but the apple also attracts the earth, which moves up to meet the apple. This attractive force is called gravitation. When this force is exerted by the earth, it is called the force of gravity. We measure the effects of the force of gravity in pounds. With how much force does the earth draw you downward? Give the answer in pounds.

Conclusion. We have learned in this chapter that much of the matter in the universe is in motion; that matter in itself is inert and helpless and that all motion and changes in motion are due to outside forces which act on the matter. We have learned what is meant by momentum, friction, and the force of gravity, and have learned something of their importance in our lives. In every movement that you make; in every piece of work that you do; and in all the activity and motion of the people and things about you scores of illustrations of the facts and laws that we have discovered will be seen. Can you learn to read this book of motion that is constantly opened before your eyes? A good scientist should be learning from it day by day.

CHAPTER TWENTY-THREE

MOTION TO AND FRO

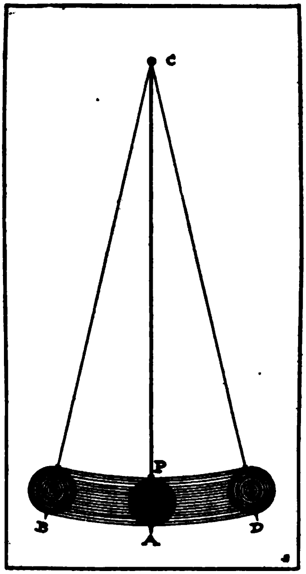


FIG. 138.

Go out of doors and observe the objects that are in motion. Notice that some of them — like the trees and their branches swaying in the wind, the heads of grain and the flowers swinging on their stems, the telephone wires hanging on their poles — move back and forth but always come to rest in the same place. These latter objects have vibratory motion, or, to use another expression, a to-and-fro motion — a very important kind of motion that is different from any of the examples of motion which were studied in the last chapter.

The waves of the sea, the light that comes to our eyes, the sound that strikes our ears, and the waves that carry the wireless telegraph messages across the sea are all the result of motion of this kind.

The pendulum and its vibration. A pendulum consists of a weight so suspended as to move freely (Fig. 138). The distance from the point of suspension to the center of the weight is the length of the pendulum. Let us study the swinging to and fro of a pendu-

lum, for in it we shall find a good example of vibratory motion.

Exercise 1. Arrange a pendulum (Fig. 138) and start it swinging back and forth.

A complete vibration is a swing from one side of the arc* to the other and back again — from *B* to *D* and back again to *B*.

A simple vibration is a swing from one side of the arc to the other — from *B* to *D*.

The amplitude of the vibration is one half of the simple vibration — from *A* to *B*.

The period of the vibration is the time required to make one simple vibration.

Exercise 2. Study the vibrations and notice carefully:

(1) That they all start from a position of rest; i.e., the pendulum is standing still at the moment when it starts its swing through the arc.

(2) That the motion is faster and faster until the pendulum reaches the point where the motion is most rapid — the bottom of the arc.

(3) That after this the pendulum goes more and more slowly until it again comes to a stop, when it turns back to repeat the motion as before.

(4) That when the pendulum comes to rest, the cord takes a vertical position, with the ball as near to the center of the earth as it can be. Why?

You will understand that it is the force of gravity that pulls the ball of the pendulum downward in its path. When it is once set in motion, it cannot stop of itself. Its momentum carries it past its point of rest

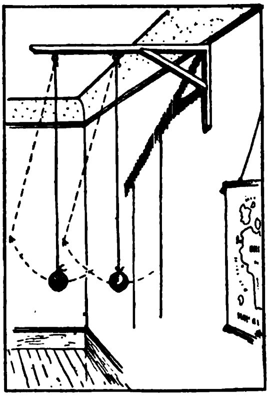


FIG. 139. Pendulums of the same length vibrate in the same time.

to the other side of the arc, from which it falls back in the next swing.

Exercise 3. Allow the pendulum to vibrate, and notice that its swing becomes shorter and shorter, and that finally, like a swing, the "old cat dies" and the vibrations cease.

The friction of the air and the friction at the point of suspension will little by little destroy the motion of the pendulum and finally bring it to rest.

The first law of the pendulum. There are several laws of the pendulum, and the best way to learn them is by the method of experiment.

Exercise 4. With watch in hand, count the number of vibrations that a pendulum will make in 10 seconds.

Repeat the experiment several times, but each time cause the pendulum to vibrate through a different arc or amplitude.

From this experiment you will learn the surprising fact that a given pendulum will always vibrate in the same period of time no matter what the amplitude of the vibration may be; that is, whether the pendulum makes a long swing or a short one, it takes the same time for the swing. This is the great and most important law of the pendulum.

How the first law of the pendulum was discovered. As he sat in the Cathedral of Pisa, Galileo, the famous

Italian philosopher, noticed the swinging to and fro of a lamp which was suspended from the ceiling. It seemed to him that the motion was very regular, although sometimes the lamp would swing through a longer space than at other times. He compared the time of the swing of the lamp with the beat of his own pulse, and by this curious method made a great discovery. He found that the lamp always took exactly the same time to swing to and fro. Here was an exact method of measuring time, and it has led to some very important inventions.

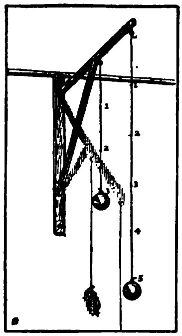


FIG. 140. The shorter the pendulum the faster it vibrates.

A second law of the pendulum. Does it make any difference whether the ball of a pendulum is heavy or light? Whether it is made of wood or of metal?

Exercise 5. Take two balls of equal size but of different materials, one of wood and the other of iron or lead. An apple and a stone of equal size may be used. Hang them side by side with cords of the same length (Fig. 139). Hold one in each hand, draw them out to the same distance, and let them go. Do they get back to your hands at the same time? Determine the period or the time of vibration by counting the number of vibrations in each case in 20 seconds. Make a number of such observations and take the average of the periods.

Try other weights, always, however, keeping the two pendulums of the same length. Would the resistance of the

air make a difference in the result if the weights were of different sizes?

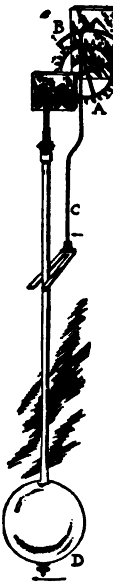


FIG. 141. The pendulum and escapement of a clock. *A* is the "escape wheel" and *B* the "anchor."

This experiment has given us the second law of the pendulum: that pendulums of the same length, but of different weights and materials, vibrate in the same time.

A third law of the pendulum. If the size and the weight of a pendulum have nothing to do with the rate of its vibration, how can one pendulum be made to vibrate faster than another?

Exercise 6. Take two weights of the same material and size, and cords of different length (Fig. 140). Which moves the faster? Is it true that the shorter the pendulum the faster it vibrates? This is the third law of the pendulum, and it is an important one.

What change is made in the pendulum of a clock that runs too slow? of one that runs too fast?

A wonderful instrument. One of the most important inventions ever made is that piece of apparatus known as the clock. Trains run by it; ships sail by it; we rise and eat and go to bed by it. It measures off time for us so that we can say, "At such an hour tomorrow I shall be at such-and-such a place" and the person who is to meet us will know exactly when to expect us to appear.

The clock is an instrument whose second hand will

divide the day into 86,400 parts; an instrument that will record accurately the flow of the immaterial stream of time, which we cannot see, hear, touch, taste, or smell. On what principle does this instrument work?

FIG. 142. Apparatus to demonstrate longitudinal and torsional vibration.

Exercise 7. Procure an old clock, remove the face, and watch the movements of the various parts. Notice the regular swing of the pendulum and observe that when the pendulum is at rest none of the wheels are moving. Review Exercises 4 and 6.

Since the movement of the wheel depends on the swinging of the pendulum, it is evident that the clock keeps correct time because each swing of the pendulum back and forth is made in a certain exact period of time. That is, it is the pendulum that measures off the time, and the hands of the clock only record the number of swings that the pendulum has made.

Exercise 8. Examine the clock further to see how the swinging of the pendulum regulates the movements of the wheels and hands of the clock. The spring and a "train of gears" (not shown in the figure) drive the escape wheel (*A*). At each vibration the escape wheel gives a slight push to the pallets (the teeth on the ends of the anchor, *B*) and this is communicated to the pendulum through *C*. In this way the pendulum is kept in motion.

Other kinds of vibratory motion. The pendulum vibrates to and fro across the direction of the string by

which it is hung. Its vibrations are therefore called transverse* vibrations. Examples of other kinds of vibrations are shown by the following experiments:

Exercise 9. Go to the toy store and buy a small wooden ball with a piece of elastic rubber cord attached to it. Suspend the ball from some convenient place so that it is at least a foot above the floor. With the hand pull the ball directly downward and then let it go. It will vibrate up and down, to and fro, in the direction of the cord. Are these vibrations made in equal times? Compare Exercise 4.

This kind of vibration is called a longitudinal* vibration, since it takes place in the direction of the length of the string.

Exercise 10. Suspend a ball by a stiff wire. Stick a pin into the ball, or paste a pointed paper upon it, so that when the ball is at rest the pin or paper is parallel with the floor. Now turn the ball partly around so as to twist the wire. Let it go, and notice the pin as it swings to and fro.

This kind of vibration is called a torsional* vibration. It is not seen so often as the other two kinds.

Conclusion. We have learned what the word "vibration" means; we have learned to recognize examples of vibratory motion all about us, and to know some of the laws that govern them. This knowledge is extremely valuable in itself, and it will enable us to glimpse vibrations that are more minute than these and therefore more difficult to see. It will also help us to believe in the vibratory motion of the molecules of matter which cannot be seen with our natural eyes. Thus we shall finally learn the method by which the scientist "sees the invisible."

CHAPTER TWENTY-FOUR

SOUND

FIG. 143. Only the song which drops back to earth tells the watcher that the little musician is still on the wing.

IN England there is a small bird called a skylark, that is a wonderful singer. It rises through the air, pouring a flood of melody from its throat, and continues to ascend until it vanishes from sight and only the song which drops back to earth tells the watcher that the little musician is still on the wing.

What is it that comes from the throat of a bird when we hear it sing? Is it matter? Is it motion? Or is it something else? And whatever it is, how does it travel to our ears? Let us investigate this thing that we call sound, and see if we can learn what it is and how it comes to us.

Exercise 1. Fill a good-sized tumbler partly full of water and gently rub the upper rim of the glass with the ball of your wet finger. Look and listen. Observe the surface of the water for signs of vibrations.

Exercise 2. Gently tap the prongs of a tuning fork upon the edge of the table and bring the handle down upon the table. What do you observe? What is the iron of the tuning fork doing? Hold a knife blade to the side of the fork and notice the rapid tap, tap of the fork upon the knife. Have you discovered a to-and-fro motion? Tap the fork again and place the handle between your teeth, and feel the movement going on. Hold it against your cheek and feel the vibrations.

Exercise 3. Strike a bell and touch the finger to it. Suspend* a piece of cork or a small pith ball so that it will touch the bell. Do you hear the sound of the bell at the same time that you see the vibratory motion of the bell? Does the sound grow fainter as the vibrations of the bell grow less?

Are you now ready to believe that there is a close relation between sound and vibration; that, indeed, sounds are produced by vibrations, and that when we begin to investigate sound we at once find ourselves dealing with the same kind of motion that we studied in the last chapter?

Sound transmitted by the air. We have learned that sounds are produced by vibratory bodies. An interesting experiment will show that sound is carried by the air.

Exercise 4. Suspend an electric bell in a bell jar, running the wires to the bell through a rubber stopper

in the top of the jar.[1] Send a current of electricity through it, and the sound of the bell will be heard by all.

Now place the jar on an air pump and pump the air out of it. The sound of the bell becomes fainter and fainter, and if the air is all removed the sound can no longer be heard.

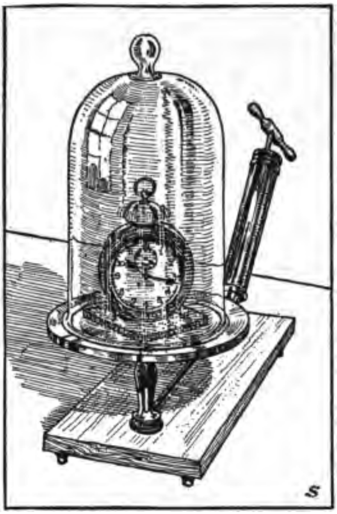


FIG. 144. As the air is exhausted* the sound becomes fainter and fainter.

Sound carried by other substances. The above experiment shows that sound will not be transmitted in a vacuum,* but that it travels through the air. Let us see if other substances will transmit sound.

Exercise 5. Place the ear at the end of a long strip of wood, — a log, a fence board, or a fish pole, — and listen while some one faintly taps or scratches the other end. Does the wood carry the sound?

Exercise 6. Sometime, when bathing, immerse the head in water and let another person who is stationed at a distance strike two stones together under the water. The sound will be distinctly heard.

[1] This experiment can be performed with an alarm clock suspended so that it will not touch the walls, or placed on a piece of felt as shown in Figure 144. When the latter method is employed the material on which the clock rests conducts the vibrations sufficiently to cause the sound to be heard faintly.

FIG. 145. The bell sends out waves in the air.

We have now learned that sound travels to the ear through air, wood, or water. That is, sound is transmitted by solids, liquids, and gases.

What sound is. Strike a bell. What is it that comes to the ear when we hear the sound? It is waves of motion in the air. As the bell vibrates back and forth it strikes the molecules of the air and sends out little waves in the air, much as waves are sent out in the water of a pond when a stone is thrown into it. When these waves strike the ear they start messages in the nerves of hearing, and when these messages reach the brain we hear the sound.

Can you now explain why a bell gives forth no sound when it rings in a vacuum?

To estimate the velocity of sound. Have you ever noticed that the flash of a gun is seen before the report is heard; that the steam from a locomotive whistle is seen before the sound is heard; and that a flash of lightning may reach the eye some seconds before the thunder comes to the ear? If we know the distance from the ear to the source of the sound and at the same time count the number of seconds of time between the

flash and the report, we may learn the velocity of sound.[1]

Exercise 7. Let two boys stand at a known distance apart, say a quarter or a half of a mile. Let one boy fire a gun and let the other boy with a watch count the time between seeing the flash or smoke of the gun and hearing the report.

The same experiment can be worked by standing at a known distance from a railroad track and finding how long it takes the sound to reach you after the steam from the whistle is seen.

Sound travels in air, at ordinary temperature, about 1100 feet per second. In water at a little above the freezing point its velocity is 4677 feet per second.

Exercise 8. During an electrical storm hold your watch and count the number of seconds between the flash of the lightning and the sound of the thunder. Suppose it is an interval of 10 seconds. How far away is the thunder?

The pitch of sounds. Some sounds have a low pitch and some a high pitch. Let us see if we can determine why this is true.

Exercise 9. Let some pupil bring to school a violin or guitar, or any other stringed instrument. Draw the bow across a string and note the sound. Fold a small strip of paper and hang it on the string; then bow the string again. Shorten the string as the violinist does when playing. Is

[1] The time it takes for the *light* to travel to the eye may be disregarded in this problem because of the very great velocity of light (page 283). The time taken by light to travel a distance of a few miles is only a very small fraction of a second.

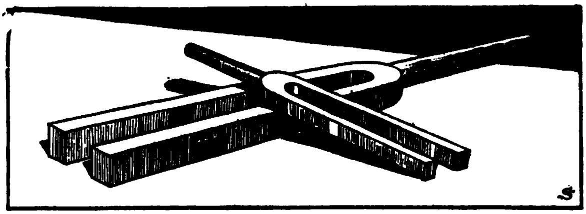


FIG. 146. Which tuning fork will give forth the higher-pitched note, and why?

the sound the same as before? Is it higher or lower? Shorten the string still more and note the sound.

What is the law of the string? The shorter the string the higher the tone. Now recall the law of the pendulum, the shorter the pendulum the more rapid the vibration. Can we now draw an inference by putting these two laws together; namely, the shorter string vibrates more rapidly and thus produces the higher tone? That is, if a body vibrates rapidly and sends the air waves against the ear in quick succession, the pitch is high; if the vibrations are slow and the waves strike against the ear less frequently, the pitch is lower.

What effect does tightening a string have on the pitch of the sound it gives forth? Does a coarse or a fine string have a lower tone? Why?

Other facts about sound. Bodies which vibrate violently and send large air waves against the ear give loud sounds. Bodies which vibrate gently and send out small waves give faint sounds. When the waves come in regular succession after each other the sound is musical and pleasing to our ears; when they come irregularly they give a harsh effect which we call a "noise."

These and many other interesting subjects relating to sound which we cannot take up at this time you will understand when you study physics and the physiology of the ear. In the meantime, when you listen to a band or an orchestra you will know that each instrument is causing its sound by vibrating back and forth and sending out waves into the air; you can think of the long line of little molecules, each of which takes up the motion as the sound comes to you; and your curiosity will surely be aroused about that wonderful instrument, the ear, which receives this great stream of air vibrations and passes it on as music to your brain. It would also be well for you to remember that we have found invisible vibratory motion where we were not looking for it, and that we may find it again in an unexpected place.

CHAPTER TWENTY-FIVE

HEAT

Go out of doors and feel the wind blowing in your face. Why does not the great covering of gas which we call the air lie quietly on the surface of the earth? Why do vast sheets of it rush hither and thither, sometimes as great storms that lash the sea to fury and spread destruction on the land? Why also do the waters of the ocean flow in great currents over their beds, carrying the warmth of the tropical seas to colder climes and the coldness of the polar oceans to the heated regions of the earth?

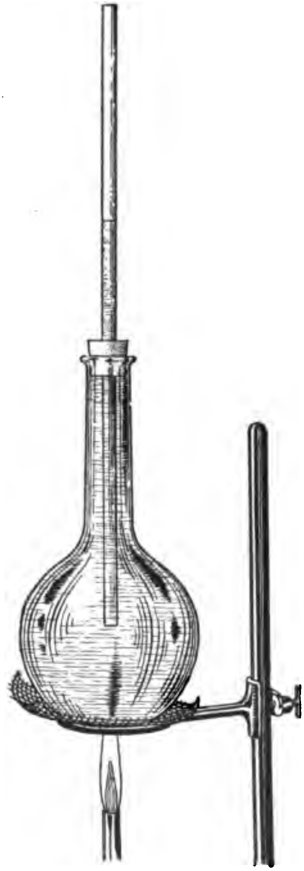


FIG. 147. When the water is heated it expands and is forced upward into the tube.

Hold your hand above the register of a hot-air furnace. Why does the heated air pour upward through the pipes? Lay your hand on a hot-water radiator. Why does warm water rise into the radiator and after it has cooled pass down into the boiler again? Here is motion for us to explain. Let us investigate the causes of these phenomena* that are so important to us all.

Exercise 1. Repeat the experiment described on page 207. Add a little red ink to the water. Allow the flask to cool. What happens?

Can you explain your experiment? Think it through and you will see that heating the air caused it to expand and part of it was forced out of the flask. When the air is cooled it occupies less space, and the water is drawn up into the flask.

Exercise 2. Arrange a flask as shown in Figure 147. Fill it full of water and stopper it, so that the water rises part way into the tube. Now heat the water. What results do you get?

Are there any more molecules in the flask of water after it is heated than before? Does it weigh any more? Would a given volume of warm water be lighter than the same volume of cold water? Would a given volume of warm air have fewer molecules in it than an equal volume of cold air? Would this make warm air lighter than cold air?

Exercise 3. Take a piece of stiff paper 4 inches square and draw the diagonals. From the corners of the square cut the paper along these diagonals to within a half inch of the center of the square. From the corners fold each alternate paper point over to the middle and bind them to the middle point by a pin. Thrust the pin through the paper into a stick or a lead pencil.

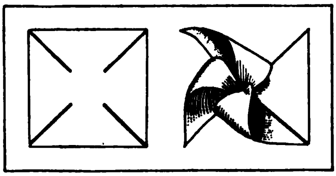


Fig. 148.

Now hold this paper windmill over a hot stove, handle

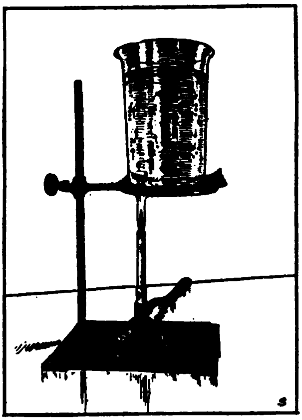


FIG. 149. Explain why there are currents in the water.

up. Do you find a rising column of air? Explain why the air rises from the stove.

Is the air near the ceiling warmer than the air near the floor? Get your answer by testing with a thermometer. With your windmill or a piece of smoke paper (page 30) test for currents of air moving in various directions about the stove.

Exercise 4. Put some fine sawdust or, better, a bit of blue litmus into a beaker glass of water. Gradually heat the water and notice the currents in the water as indicated by the movement of the dust particles (Fig. 149). Does the warm water rise of its own accord? Or, rather, does not the cold, and therefore heavier, water settle to the bottom and force upward the warmer and lighter water? If this is the case, what force causes heated air and heated water to rise? Explain what causes the movements in the water.

Exercise 5. Set up a piece of apparatus like that shown in Figure 150 to represent a hot-water heating system. The flask *A* corresponds to the furnace, *B* and *C* to the pipes and radiator of the heating system, and *D* to the expansion tank, which is usually placed in the attic or upper part of the house. To show the currents add litmus or other colored liquid to *C*.

Exercise 6. Examine a hot-water heating system. Trace

the pipes through the house, and explain the course that the water takes. Why is an expansion tank necessary?

Some questions about heat. We have now learned that heat expands air and water, but we have still to ask what heat is and why the air and water expand when they are warmed. To answer these questions we must return to the subject of vibratory motion, which, in nature, we meet again and again. We will repeat an experiment made at another time and for another purpose.

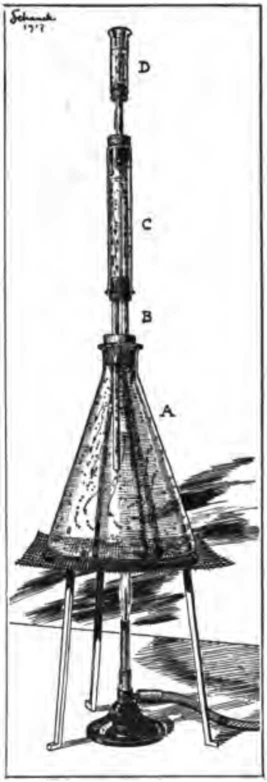


FIG. 150. Apparatus illustrating a hot-water heating system.

Exercise 7. Take a piece of iron, place one end of it on an anvil or solid stone, and hammer it vigorously. It becomes warm; heat is produced in the iron. Hammer it still more, using greater force. It develops greater heat and will soon become uncomfortably warm. The greater the pounding, the greater the heat.

What heat is. What change does the pounding make in the iron? That is, what is heat? Scientists tell us that the molecules of all substances are always in motion

FIG. 151. Diagram of a hot-water heating system.

to and fro; that they constantly dance back and forth with a vibratory motion. When the movement of the molecules is slight, the substance is cold. When the molecules move very rapidly, the substance is hot. Heat, then, may be thought of as the motion of the molecules, and when we pound the iron we jar the molecules and set them to vibrating more rapidly.

Heat is easily recognized by the sensation of warmth which it gives to the touch. That is, when we touch anything and feel the molecules pounding with great vigor against our hand, we say it is hot. If heat is the motion of the molecules, what is cold?

Why heated substances expand. Can your own imagination now tell you why heated substances expand? Suppose the molecules of the iron are set to vibrating more vigorously, will they not drive each other farther apart? Think over this matter, and when you lay your

finger on the bulb of a thermometer and see the mercury rise in the tube, picture in your mind how you are quickening the millions of little molecules in their dance.

Conduction of heat. When heated air or heated water moves from one place to another, it of course carries with it the heat it contains. This method of transporting heat is called convection. We speak of convection currents in the water and the air. Heat is transmitted in another way also, which we can illustrate by an experiment.

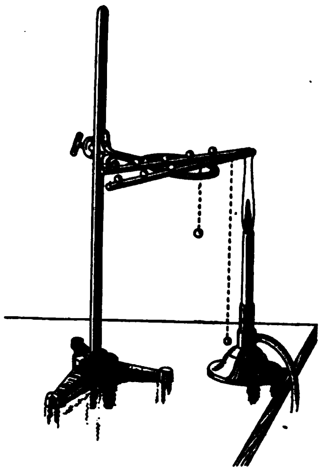


FIG. 152. One rod is a better conductor of heat than the other.

Exercise 8. Hold one end of an iron poker in the fire. The heat is transferred from one end of the poker to the other. Explain what you think the molecules are doing as the heat travels along the poker.

Exercise 9. Take a piece of iron wire two or three inches long; fasten one end to the head of a match, and hold the other in the flame of a candle or a lamp. What are the results?

In the above experiments the heat travels by conduction through the iron. The motion passes from molecule to molecule as motion passes from block to block in a row that has been set up and knocked down

by a child. Heat travels by conduction through liquids and gases as well as through solids, but in liquids and gases the molecules are free to leave their places and travel about, and, as we have learned, heat may be transported by convection also.

Exercise 10. Arrange a glass rod and a metal rod, or a copper rod and an iron rod, as shown in Figure 152. Now, with drops of wax, fasten small marbles or large shot along the rods at equal intervals. With an alcohol lamp or a Bunsen burner heat the ends of the rods equally. What results do you get?

Do all bodies conduct heat alike? What is the philosophy of the cloth "holder" commonly used with hot dishes? Is a wooden handle or an iron handle better for use on a hot iron? Why are boilers and steam pipes wrapped with asbestos? What kind of clothing should we wear in cold weather? in warm weather? With what would you wrap a water pipe to protect it during very cold weather? What is between the two layers of a thermos bottle? Why should this be an excellent protection from heat or cold?

Exercise 11. Place your bare hand or foot upon the oilcloth and then upon the carpet next to it. Which is the warmer? Test with the thermometer and see how mistaken you are.

Why does the oilcloth seem colder than the carpet? Why does a marble-top table seem colder than a wooden table in the same room? The oilcloth and the marble are better conductors of heat than the carpet and the wood. They therefore conduct more heat away from the

hand or foot and for this reason feel colder. Iron conducts heat about 100 times as well as water and about 2500 times better than air. Find out what materials are in the walls of an ice box. Why does a fireless cooker hold heat?

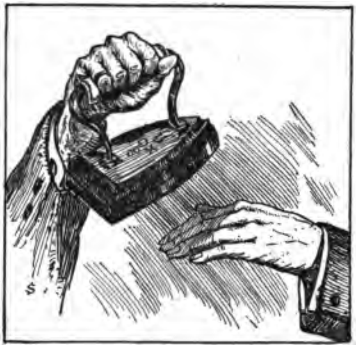


FIG. 153. Heat is given off by radiation from the iron.

Radiant heat. Heat comes to us from the sun. It travels across space in which there is no air through which it can be carried by convection or conduction.

Exercise 12. Suspend a piece of iron by a wire and heat it with a gas burner. A common flatiron heated and then held as is shown in Figure 153 may be used in this experiment. Hold the hand beneath the iron. The air is rising and the heat will not reach the hand by convection or conduction; yet a sensation of warmth is felt by the hand.

The heat is given off by radiation from the iron and is called radiant heat. The explanation of how it comes to the hand will be deferred until a later chapter (page 336).

Sources of heat. We may discover some of the sources of heat for ourselves.

Exercise 13. Find out how the Indian produced fire. Repeat his experiment in some form. At least, brush your dry hand briskly over your coat sleeve, rub a piece of metal upon a smooth board, or draw a nail from a hard board and note that heat is produced by friction.

In connection with these experiments review Exercise 7. Then you may be prepared to believe that whenever motion is checked, heat is produced. Motion is, therefore, a source of heat. What causes a meteor to become hot when it falls through the air?

FIG. 154.

Exercise 14. Strike a match and answer one or two questions. (*a*) How much heat was produced by the friction? The answer is, enough to raise the chemicals on the match to the kindling point. (*b*) What happens next? The oxygen of the air is now able to unite with the chemicals of the match head to produce more heat.

Why do we open the draught of the stove or furnace when the fire burns low? Note the heat produced as the mason puts water on the lime in the process of making mortar. Perhaps you can make this experiment for yourself.

Another and very common source of heat is chemical action. Great supplies of heat that can be released in this way are found in our stores of wood and coal. From what source does the heat come that warms your own body?

Exercise 15. Introduce a small, thin iron wire into the circuit of an electrical battery. The wire is a poor conductor of electricity and for this reason the flow of the electricity is

obstructed, the result being that heat is produced.

This experiment shows that a third source of heat is electricity. The incandescent filament of an electric lamp is a familiar example of a body heated by electricity.

FIG. 155. Our greatest, and in the end our only, source of heat is the sun.

Exercise 16. Step from the shade into the bright sunshine. What change in temperature do you note?

Secure a reading glass and concentrate the rays of the sun in a fine point on a piece of cloth or paper. Hold the glass steady for some time. What happens?

A fourth source of heat is the sun. It warms the whole earth and the other members of the solar system, and in the end it is our only source of heat, for it is the sunshine that enables plants to build the food that warms our bodies and the wood and coal that heat our homes. The sun also gives us our water power by lifting the water of streams to the mountain tops, and the heat of the sun causes the great currents of air that turn our windmills and drive our ships across the seas. Silently as the grass covers the hillsides in the spring the heat of the sun leaps through ninety millions of miles of space to us; but without this mighty force all life and motion in the world would soon be stilled, and our earth would be but a frozen ball swinging onward through space.

CHAPTER TWENTY-SIX

HOW TO MEASURE TEMPERATURES

Do you already know that heat and cold do not mean two different things? Heat and cold are relative terms used to show whether a body or a substance has more or less of heat. In common speech we say of anything which is warmer than our body that it is warm; if it has a lower temperature than our body we say it is cold. In both cases, however, there is motion among the molecules. The difference is that they move faster in the warmer body and more slowly in the colder body.

Measuring temperature. How shall we measure temperature? Within certain limits the nerves in our skin enable us to do this. Let us see how accurate they are.

Exercise 1. Provide three dishes of water, with the water in the first as hot as the hand will endure without scalding; the second filled with water which has just come from the well or hydrant; and a third containing ice water.

(1) Place the hand in the first dish for a moment or two and then in the second. The latter will feel cold.

(2) Place the other hand for a moment in the third dish and then transfer it to the second. The latter will now feel quite warm.

Exercise 2. Put your hand into water which has been standing in the room for some time. Which is warmer, the air or the water? After you have judged the case with your hand, try it with the thermometer. Both air and water will be found to be of the same temperature.

It seems, then, that while the nerves of the skin can be used in a general way to tell temperatures, they

cannot be depended upon for great accuracy. They can only compare two or more bodies which are so near together that they may be tested at the same time; and they cannot compare two substances of different kinds. We see, therefore, that we need a more accurate instrument for measuring temperatures, and for this purpose we have the thermometer.*

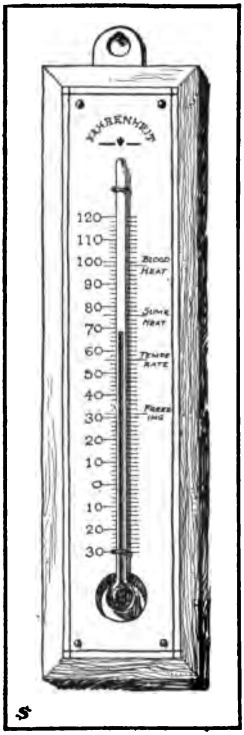


FIG. 156.

The thermometer. Every home and schoolroom should have at least one fairly good thermometer. One can be purchased for from twenty-five cents to a dollar.

Exercise 3. Study the construction of the thermometer. Note the tube closed at both ends, the bulb, and the graduation. It will be more convenient for many purposes if the thermometer is not fixed to a board or frame of iron. Hold the bulb in your hand for a minute. The mercury rises. Explain why. Finally it comes to a point beyond which it does not go. Why does it stop at this point?

The Fahrenheit and centigrade scales. The thermometers used in different countries are exactly alike in the construction of the tube but differ in the way

they are marked. The two scales most commonly employed are the Fahrenheit and centigrade.*

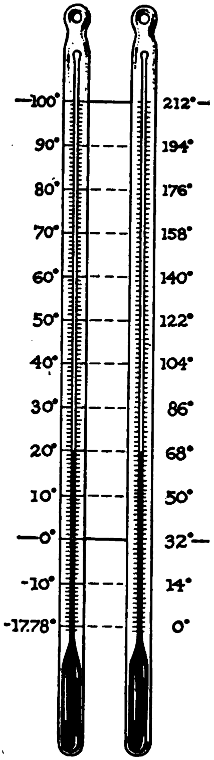


FIG. 157. Comparison of the centigrade and Fahrenheit thermometers.

Exercise 4. Test the graduation of your thermometer, as follows: Place several coarse pieces of ice in a dish containing pure water and allow it to stand for a few minutes. Stir the ice in the water thoroughly to make the temperature the same in all its parts. Now place the thermometer in the water and note the temperature. If you are using a centigrade thermometer, the temperature should be at zero. If you are using a Fahrenheit thermometer, the temperature should be 32 degrees.

Add more ice and note the temperature. See whether the temperature differs when the bulb of the thermometer is against the ice and when it is merely in the water. Very gradually heat the water, constantly stirring the ice and testing with the thermometer. What is the freezing point of water? What is the melting point of ice?

It requires nearly four fifths as much heat to melt a pound of ice as it does to raise from the freezing to the boiling point the water that comes from the ice. During the melting process the temperature is not raised at all. The heat is used in changing the water from the solid

to the liquid state. When we buy a block of ice, therefore, we are buying something that has a great capacity to absorb heat.

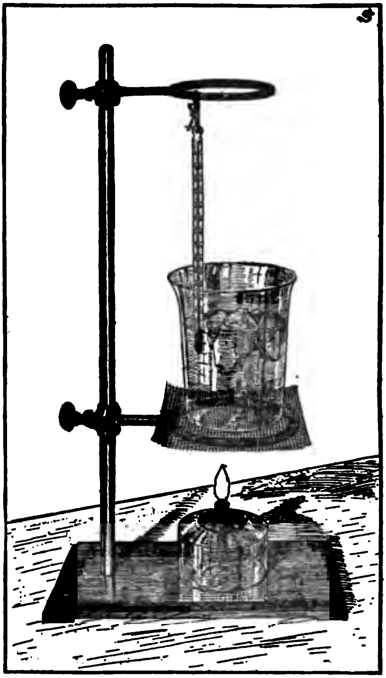


FIG. 158. The melting of the ice absorbs heat, and the temperature of the water does not rise until all the ice has disappeared.

Exercise 5. Partly fill with water a flask (Fig. 160) provided with two openings. An ordinary teakettle may be used. In one opening place a thermometer. Bring the water to the boiling point and note the temperature of the steam and also of the water. Continue the boiling for several minutes, placing the bulb of the thermometer alternately in the steam and in the water.

Does the thermometer show a higher temperature if the heat has been applied to the water for several minutes after it has begun to boil? The mercury remains at a fixed point as long as the water continues to boil. What is the boiling point of water? At what temperature will water vapor begin to condense?

We have now determined two points on our thermometer: the freezing and the boiling point of water.

Figure 157 shows the fixed points on the centigrade (C.) and the Fahrenheit (F.) thermometers. Notice that the difference between the freezing and the boiling point of water is divided into 100 degrees on the centigrade thermometer and into 180 degrees on the Fahrenheit thermometer, and that therefore 100 degrees C. equals 180 degrees F.

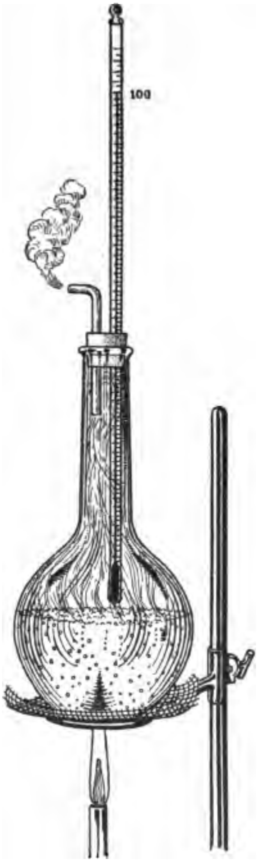


FIG. 159. The evaporation of the water takes up heat, and the temperature of the water and steam does not rise above the boiling point.

Freezing mixtures. The Fahrenheit thermometer has a point marked 0 which is 32 degrees below the freezing point of water. When we wish to freeze ice cream we sprinkle salt liberally over the ice which is around the freezer. How does salt help to freeze ice cream?

Exercise 6. Take two dishes of snow or ice and test the temperatures. Stir a considerable quantity of salt into one dish. Again test the temperatures. Consider the following questions:

(1) Does the salt cause the snow or ice to dissolve more rapidly?

(2) What is required in order that a solid may be changed into a liquid? Review the first part of Exercise 4.

(3) If heat is required, must the object which furnishes the heat become colder?

(4) Does salt water freeze at a lower temperature than water that contains no salt?

Exercise 7. Place a small, tightly corked vial of sweetened cream (water may be used for a " make believe " sweetened cream) in the midst of the dissolving ice and salt. What happens? What would you have if you should do this on a large scale? If you should find the vial broken, how would you explain the circumstance?

Can you now explain clearly why salt is used in freezing ice cream?

In the year 1714 a German named Fahrenheit invented the thermometer which bears his name. He packed it in a mixture of chemical salts and snow and marked as zero the lowest point of the mercury that he could obtain in this way. In 1742 the centigrade thermometer was invented by Celsius, a Swede.

Heat required to evaporate liquids. Review the second part of Exercise 4. It requires almost $5\frac{1}{2}$ times as much heat to turn boiling water into steam as is needed to raise the same amount of water from the freezing to the boiling point. By experiment you can prove that heat is required to change a liquid into a gas.

Exercise 8. Moisten your hand with ether, alcohol, or gasoline. As the liquid turns into a gas, the hand feels cold. The hand is robbed of a large amount of heat to produce the gas.

Exercise 9. Place a drop or two of water upon a board and set on the water a watch glass containing a small quantity of ether. Now cause the ether to evaporate

FIG. 160. An ice factory on a small scale. The evaporation of the ether takes up heat and freezes the watch glass to the board.

rapidly by blowing a current of air across it. The watch glass will be frozen to the board.

What is the effect produced by perspiration on a hot day? Why do we suffer especially from the heat in humid summer weather?

Ice making. In an ice plant ammonia gas is drawn into a pump and put under great pressure. In this way it is converted into a liquid. The liquid ammonia is then allowed to escape as a gas through coils of pipes that run through a tank of brine (*B*). The evaporation of the ammonia takes up heat and makes the pipes and the brine very cold. The ammonia gas is then again sucked from the pipes by the pumps, reduced to a liquid, and once more allowed to escape as a gas, and so the process is continued.

The brine about the pipes containing the ammonia does not freeze, because of the salt that is in it (page 257), and a second pump causes it to circulate through a larger tank (*C*). The ice is produced by lowering deep, flat-sided iron vessels (*D*) filled with distilled water into this tank until the water is frozen. The blocks of ice are loosened from the walls of the vessels in which they are frozen by dipping the vessels in hot water. In cold-storage plants the pipes containing the cold brine run through the rooms that are to be chilled. When

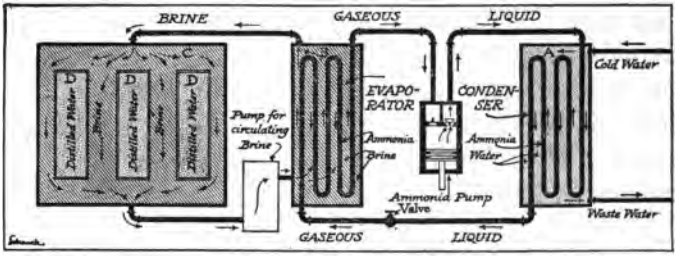


FIG. 161. Plan of an ice-making machine. (Diagrammatic.)

the gaseous ammonia is condensed heat is given off, and it is necessary to keep cold water flowing about the pipes in which the liquid ammonia is contained.

Exercise 10. Visit an ice factory or a refrigerating plant and learn how the low temperature is produced.

Temperature and quantity of heat. We must remember that the thermometer is only useful to measure the intensity of heat — how hot a body is — and cannot be used directly to measure the quantity of heat. A comparatively small amount of heat will raise the temperature of a fine platinum wire to a temperature of 1600 degrees. The quantity of heat in this case is very small, though the temperature is very high. It is therefore important that we should keep clearly in mind the difference between temperature and quantity of heat. Temperature depends upon the rapidity of the vibration of the molecules, and this is measured in degrees by a thermometer. The amount of heat which a body contains depends upon the weight and the material of which it is composed, as well as upon its temperature.

If we should take a cupful of water from a lake and

test with the thermometer both the water in the lake and the water in the cup, the temperature of the water in the two cases would be the same. On the other hand, it is evident that the total quantity of heat in the cup would be only a small fraction of the total amount of heat in the lake. What would be the temperature if we should take 2 cupfuls from the lake? What quantity of heat would be in 2 cupfuls as compared with the heat in 1 cupful? Three cupfuls would have the same temperature as 1 cupful, but 3 times as much heat. The quantity of heat depends upon the amount of water taken.

Exercise 11. Fill a pint and a quart cup from the same source of hot water. Take the temperature with the thermometer in each case. What is the temperature and what is the quantity of heat in each case?

Exercise 12. Take a measured amount of water, find its temperature, and mix it with an equal amount of boiling water. When the hot and cold water are thoroughly mixed, take the temperature of the mixture.

To measure the quantity of heat. Heat, like every other useful thing, is bought and sold, and therefore it must be accurately measured. Liquids are measured by the quart or the liter; solids, by the pound or kilogram. Heat may be measured by the use of one or the other of two units: (1) the British thermal* unit, based on the pound weight and the Fahrenheit degree, and (2) the calorie, based on the gram weight and the centigrade degree.

A British thermal unit (B.T.U.) is the quantity of heat required to raise one pound of water one degree Fahrenheit. Weigh out a pound of water and examine the degrees marked on a Fahrenheit thermometer. Have you a clear idea of what a British thermal unit is?

Exercise 13. Weigh out a certain quantity of water, say 2 pounds. Take the temperature with the Fahrenheit thermometer. Place the water on a stove or a hot radiator, or apply a flame to it for some time. Before the water boils, remove it from the stove or radiator, stir it thoroughly, and note the temperature.

If the original temperature was 60 degrees and the final temperature is 130 degrees, then 2 pounds of water have been raised 70 degrees, and the amount of heat absorbed by the water, as the result of heating, is $2 \times 70 = 140$ British thermal units (B.T.U.'s).

Coal is usually bought at a fixed price by the ton. The power of coal to produce heat varies greatly, and since it is the heat we want, it would be more scientific if we had our coal tested so that we could know accurately how many British thermal units a ton would produce. This is done by many manufacturing companies that use a large amount of coal. The amount of heat in coal is determined by finding how much a pound of the coal raises the temperature of a given number of pounds of water.

A calorie is the quantity of heat which is required to raise 1 gram of water 1 degree centigrade.[1] A gram

[1] In tables showing the heat values of foods for men and animals the large Calorie (written with a capital C) is the unit used. This is the amount of heat required to raise the temperature of 1 liter of water 1 degree centigrade. It is equal to 1000 calories as defined above.

of water is a cubic centimeter. Measure or weigh it out and see how much it is. Examine the degrees on a centigrade thermometer. Is a British thermal unit or a calorie the larger unit?

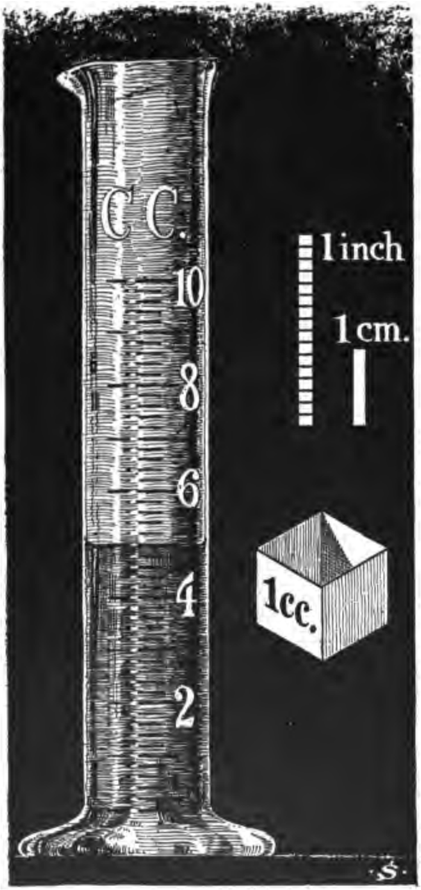


FIG. 162. Exact size of measures that hold 1 cubic centimeter and 10 cubic centimeters. What is a calorie?

Exercise 14. Weigh out a certain quantity of water, say 750 grams. Take the temperature with the centigrade thermometer. Heat it for a time. Remove the source of heat, mix the water thoroughly by stirring with the thermometer, and again take the temperature.

If the difference between the two temperatures was 58 degrees, the amount of heat absorbed by the 750 grams of water would be $750 \times 58 = 43{,}500$ calories.

Exercise 15. Weigh a certain amount of hot water, using either the pound or

the gram weights. Take the temperature. Allow it to stand for some time and take the temperature again. How many heat units has it lost during that time?

Exercise 16. Place a pail on one pan of a balance and enough weights on the other pan to balance it. Place a flatiron on the pan with the weights and pour enough water into the pail to balance the iron. Now place the iron in the pail with the water. Set the pail and its contents on the stove in a place that is warm, but not hot enough to bring the water to the boiling point. Let the pail stay on the stove until the iron is warmed in all its parts and the iron and water are thus brought to the same temperature.

Provide two vessels, with the same weight of cold water, at the same temperature, in each. Take the temperature. Set the flatiron in one of the vessels of cold water and pour the water from the pail into the other. At the end of a certain time, — for instance, three minutes, — take the temperature of the water in both vessels. The water should be thoroughly stirred in both cases, before taking the temperature.

Different substances have different heat-holding capacities. You are now ready to answer some interesting questions and to make a very practical application of the knowledge gained in the last exercise. Which of the two samples of cold water gained the more heat during the three minutes of time? Which contained more heat, the hot iron or the equal weight of hot water? When you go sleigh riding, which would be better to place under your feet as a foot warmer, a hot flatiron, wrapped in a woolen cloth, or an equal weight of water at the same temperature in a hot-water bag?

A given weight of water holds more heat than an equal weight of any other common substance at the same temperature. Pound for pound it contains 8 times as much heat as iron, 10 times as much as copper, 20 times as much as tin or silver, and 20 times as much as mercury. Give two reasons why in temperate climates large lakes make the climate of places near them cooler in spring and warmer in autumn.

CHAPTER TWENTY-SEVEN

PRACTICAL THERMOMETRICAL PROBLEMS

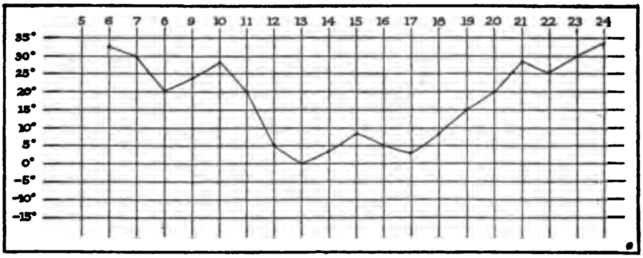


Fig. 163. Mean daily temperature graph at Albion, Michigan, from December 6 to December 24, 1914.

Exercise 1. Hang a thermometer in your room at home. By observation and experience learn what is meant by "ordinary temperature," C. degrees and F. degrees, of the room at various hours of the day and night and for several days. Preserve in tabulated form the results of your observations.

Exercise 2. At the schoolhouse make hourly observations of the thermometer readings and preserve them in a blank book provided for the purpose.

Exercise 3. At the end of each week compute the answer to the following questions and record the results in a notebook. What is the mean, or average,* hourly temperature for each day you have observed? What is the mean daily temperature for the days you have observed? Take these reports home to your parents.

Exercise 4. Construct a graphic chart of your observations similar to Figure 163. Take the average of three observations of the thermometer at 7 A.M., 2 P.M., and 9 P.M., as the mean daily temperature. Make a mark on the chart for each day, showing the mean daily temperature for that

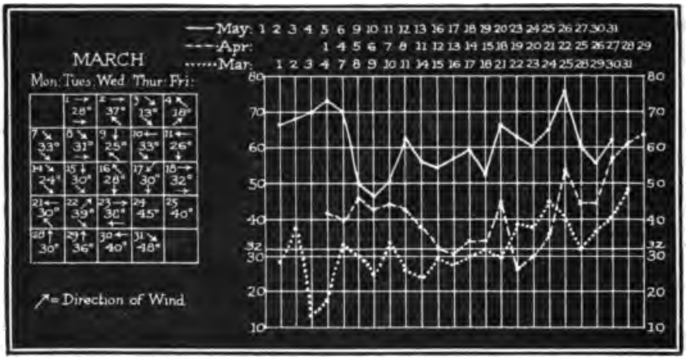


FIG. 164. Weather records kept by a class in the Jefferson Street School, Grand Rapids, Michigan.

day. At the end of the month draw a curved line joining all the points. The chart will then show at a glance the variations in temperature for the entire time. The curved line is called a thermograph* or temperature graph.

Be sure that you are able to read the thermograph. From Figure 163 determine what was the mean temperature for December 12. What was it for December 9? When was the highest temperature reached and what was the mean temperature at that date? When did the lowest temperature occur? Notice that the temperature must have been considerably lower than zero at some time in the day in order to give an average of zero.

A more instructive temperature graph and one from which many valuable lessons may be learned may be constructed from readings taken hourly for a week or more. It requires some trouble to take the readings, especially through the night, but three or four of the

class could easily organize themselves into relays* and thus obtain all the data needed.

When the graph has been constructed, it can be placed upon the blackboard and various facts read from it:

(1) Study the daily range of temperature.

(2) From the first graph construct a second, showing the average temperature for the hours between sunrise and sunset, and another for the hours between sunset and sunrise. Study the range between these limits.

(3) From the original graph, note the hours of maximum and minimum temperature.

Study the chart shown in Figure 164 until you can read every fact on it. What was the highest temperature in March? in May? What was the lowest temperature in each of the months? The arrows in the calendars show the direction of the wind; the one at the top of a square shows the direction in the forenoon, the lower one in the afternoon. Prepare a similar chart for yourself.

Exercise 5. Let several persons hold a thermometer in the hand until the mercury has risen as far as it will go. After each test, allow the thermometer to cool. Tabulate the tests and compare. It will probably be found that the temperature of the hands of the different persons varies somewhat.

Exercise 6. Place the bulb of the thermometer in your mouth and under the tongue, holding it there for at least 2 minutes. Note the temperature, which will be found to be about 98 degrees F., provided you have a reliable thermometer and your body is at a normal temperature. This is the method by which the doctor learns whether you have a

higher temperature, — or, as the case may be, a lower temperature, — than you ought to have.

Bacteria. To take the temperatures of a number of the members of the class in this way, the pupils will need one after another to take the bulb of the thermometer into their mouths. Before they do this, however, we should pause long enough to study some facts which have a very great and practical interest at this point.

The sanitarian* will tell you that there is a large number of bacteria in your mouth all the time, whether you are well or ill. Bacteria are very low forms of plant life, — tiny sacs or cells, as they are properly called. They are alive and are composed of a curious jellylike substance called protoplasm.* They are present in large numbers in earth and water, and when they gain access to liquids which contain material suitable for their growth, they multiply with great rapidity, so that a single bacterium, if placed in milk or some other suitable food, will develop into many millions in the course of one hot night. Most bacteria are harmless, and many of them are useful, but some of them grow in our bodies and cause illness. These dangerous kinds are called germs, and some of them might exist in the mouth of one person without doing him any apparent injury. If, however, they were transferred to the mouth of another, they might grow and produce disease.*

Exercise 7. Place some white of egg in a test tube. Set the tube, along with a thermometer, in a vessel of water and gradually heat the water. At what temperature does the white of egg coagulate* or harden?

The protoplasm of which bacteria are made is very similar to the white of the egg, and like the white of the egg it is coagulated by heat. This, of course, kills the bacteria. After the thermometer has been in one pupil's mouth, and before it is used again, it should be thoroughly rinsed in boiling water to kill all possible germs. It may then be dipped in cold water to bring the mercury below the temperature of the body. In this way let the thermometer be sterilized* and the mouth temperatures of several pupils be taken. Tabulate your results and compare.

Exercise 8. Fill a vessel with ice water. Feel the temperature with the hand. Set it on the stove and heat it, holding a thermometer in the water and testing the heat with the hand from time to time.

The temperature of the water of a cold bath is from 33 to 60 degrees F.; of a temperate bath from 70 to 85 degrees; of a tepid bath from 85 to 92 degrees; of a warm bath from 92 to 98 degrees; and of a hot bath from 98 to 112 degrees. Become familiar with the feel of the water at the different temperatures mentioned.

Exercise 9. Study the effects of various exposures made by placing thermometers in the shade, in the sun, in the wind, near the ground, at an elevation, in the open air, in some secluded place in an angle of the house, in a well, in a valley, on a hill, and in other locations. In a word, cultivate the habit of observation and the power to interpret your results intelligently.

By the experiments that we have performed we have learned that the thermometer is one of the most useful of instruments, a practical tool which has frequent uses

in our everyday life. By it we regulate the heating of home or office, and by it the janitor of the school or church may know whether he is furnishing just enough heat, not too much or too little, to make people comfortable. By the use of the thermometer in the kitchen we may ascertain the proper temperature of the oven so that the best results in baking may be obtained, and in a time of sickness the good doctor visits us and by the use of his thermometer gathers information on which to form his judgment as to the condition of the patient. Like a good scientist he does not guess, but accurately measures the temperature of his patient in order that he may know.

Perhaps you will have enough interest in measuring temperatures to make other experiments.

CHAPTER TWENTY-EIGHT

THE PHOTOGRAPH

A timid girl or an embarrassed boy has placed herself or himself before a mysterious box with its one eye and has put on a "pleasant expression." There has been a sudden click of some part of the apparatus; the operator has disappeared into a dark room and made a few passes over the glass plate, to emerge presently from his hiding place and announce with a reassuring smile, "It is splendid and you can see the proofs day after tomorrow." A negative has been produced by the photographer and from it he will print the positive which, when properly finished and mounted upon a card, is ready to astonish or please the subject's friends.

Photography a complex process. Very few people understand the many changes which occur in widely different substances before a photograph is produced. Truly the highest skill and ingenuity of man have been exercised before the picture is complete, and the ends of the earth have made their contributions; the animal, vegetable, and mineral kingdoms have all been drawn upon. Silver from the mines of Nevada, "pyro" from the oak forests of the Levant,* sodium chlorid from the salt wells of Michigan, sodium nitrate from the nitrate beds of Chile in far-away South America, iodin and bromin from the ocean, glass from the factories of Europe, — these and many other products are required; and for making both plate and print there is needed the mighty influence of the light which has made its long journey

of millions of miles (how many?) from the sun to the earth.

We may not explain away all the mysteries of the photographic process, — no one can do this, — but we may gain much profit by unraveling some of the ends of the complex problem and may learn the better to appreciate that much prized invention of the present age, the kodak picture.

Definition of photography. The word "photograph" is formed by combining two Greek words, *photos*, meaning "light," and *graphein*, "to write." Literally, therefore, the word means "light-writing" or "writing by the light." Photography is the art of fixing upon a sensitive plate or paper, through the agency of light, an image of any given object. A review of the history of photography will perhaps serve as the best introduction to the subject.

The first camera. The first camera was simply a darkened room to which light was admitted through a single small hole in the window shutter. When the sun shone brightly, a faint, inverted image of the landscape outside could be seen on the white surface of the wall inside. This fact was discovered and used by an Italian philosopher, Giambattista della Porta, in the last half of the sixteenth century, although it is claimed that the same discovery had been made by Roger Bacon, who lived in the thirteenth century. (Who was Roger Bacon?)

Exercise 1. Close all the shutters of the schoolroom and allow a ray of sunlight to pass in through a tiny opening.

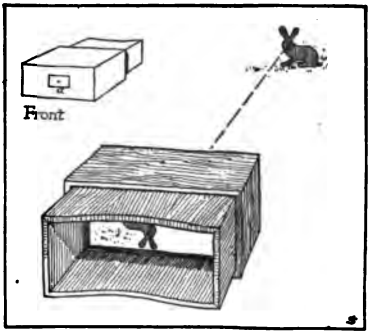


FIG. 165. The camera obscura.

The dust in the air, which you had not noticed before, will make visible the rays of light. You can make them more plainly visible by knocking together two blackboard erasers, to increase the number of dust particles in the air. Do the rays of light travel in a straight line? Can you see around a corner?

Exercise 2. Allow the light to fall on a white wall or hold a sheet of white paper or cardboard in its path. Notice the images of outside objects formed upon this background. Because light travels in straight lines, everything in the picture is upside down. Consider carefully why this must be so.

The camera obscura. The camera of today has certain improvements by which the brightness and sharpness of the image can be increased and its size regulated. For example, since the room and the landscape are fixed in position, they cannot be adjusted to each other so that the image will be of the desired size, and this difficulty suggested the use of a movable screen on which the image would fall. This in turn suggested a darkened box which could be moved from place to place as desired. Dealers in physical apparatus now have for sale a reproduction, made for pupils' use, of the first camera obscura (dark chamber). It consists of two boxes which "telescope" on each other, one box

containing a pinhole, the other with a ground-glass plate (Fig. 165). A crude camera may be made as follows:

Exercise 3. Take an empty tin can without a cover. Make a hole of some size in the bottom of the can. Paste a piece of tin foil over this opening and prick a pinhole in the middle. Cover the open end of the can with a thin tracing paper or cloth. Turn the pinhole toward a candle flame, and an image of the flame will be seen upon the paper. Notice that it is inverted and that the size of the image depends upon the distance of the pinhole from the candle. The image will be seen more plainly if a dark cloth is used (after the fashion of the photographer) to screen the eye from the outside light. Learn by experience whether you get a clearer image when the pinhole is very small or larger.

An improvement in the camera. Della Porta made another important improvement upon the camera obscura when he found that by placing a double-convex lens in the opening a much brighter and more sharply defined image was obtained.

Exercise 4. Procure a convex lens (a reading glass may be used) and note how it forms an image. Hold the lens over a printed page and find by trial the place where it must be held to see well; then notice that the letters seem larger than they really are. You do not see the letters, but rather their image.

Examine the image on the ground glass in the back of a camera. Does the lens of the camera admit more light than the pinhole in the camera obscura, or less?

The rays of light from external objects enter the lens and form a bright image of the object in its natural colors, smaller in size and in an inverted position. Figure

166 shows how such a camera was first used. The only way to preserve the pictures produced was to copy them; so the artist shut himself in darkness as he worked. A very complete or perfect picture of the object was not obtained, but the introduction of the lens was a great improvement, — one which made possible further progress in the photographic art.

FIG. 166. An early form of the camera.

The photograph. It is a matter of common experience that when the skin is exposed to the hot sun for some time, it becomes darkened or "tanned." Some chemical action takes place which changes its color. The great Aristotle (384–322 B.C.) noticed this fact and recorded it in one of his books. He did not know the real significance of what he had observed, — that light can cause chemical changes; but later it was discovered that light does cause these changes, and this fact is the basis on which the art of photography rests.

The other half of the discovery was made in 1727 by J. H. Schutze, a German, who obtained the first actual photographic copy of writing by placing the black copy over a mixture of chalk and silver nitrate and exposing it to sunlight. By doing this, he came face to face with the basic principle of all photography, which is that silver

salts turn black when exposed to the light. You may observe the fact by repeating this historical experiment.

Exercise 5. Make a thin paste of silver nitrate and powdered chalk. Moisten a piece of filter paper with the solution and spread the paper out on a flat surface. Lay some opaque object, like a key, on the paper and expose it to the direct rays of the sun. The light will break down the molecules of the silver nitrate that are not protected from the sunlight by the key, and will form a new compound which is of a different color.

In 1802, Sir Humphry Davy discovered that silver chlorid was much more sensitive to the light than silver nitrate. We may repeat his experiment as follows:

Exercise 6. First moisten a filter paper with a strong solution of common salt and then drop it flat into a solution of silver nitrate.

$$\underset{\text{silver nitrate}}{AgNO_3} + \underset{\text{sodium chlorid}}{NaCl} \rightarrow \underset{\text{silver chlorid}}{AgCl} + \underset{\text{sodium nitrate}}{NaNO_3}$$

Silver chlorid is deposited by this process on every part of the paper.

Exercise 7. Take the paper from the solution, spread it out as before, cover it with a key, and expose it to the sunlight.

Of course your picture fades out, as did those produced by Davy, who could find no way to prevent this.

The daguerreotype. In 1832, a Frenchman named Daguerre discovered a method of "fixing" the picture. A copper plate was coated with silver and highly polished. This plate was then exposed to vapors of iodin, thus forming silver iodid.

$$\underset{\text{silver}}{Ag} + \underset{\text{iodin}}{I} \rightarrow \underset{\text{silver iodid}}{AgI}$$

The plate was then placed in a camera, the subject was placed in position, and the exposure was made. The time of exposure was about 20 minutes. Next, the plate was taken to the dark room and exposed to the vapors of mercury at 60 or 70 degrees, and afterwards placed in a solution of gold chlorid and sodium hyposulfite. By this process a brilliant and very permanent picture was produced. In this way was begun one of the most marvelous discoveries ever made. Daguerre received a pension of 6000 francs from the French government in appreciation of the fact that he freely gave the details of his discovery to the world. Let some pupil bring to the class a good example of a daguerreotype. Many of those made more than a half century ago are as bright and perfect today as when first taken.

How modern photographs are made. The method of making a modern photograph is best found out by the principle of "learning to do by doing." When you buy your camera, ask for the circular of information which goes with it; and by carefully following directions you can, through practice, become an adept.* The chemistry of the process we shall explain in a general way.

When you buy a photographic plate or film, you receive a square of glass or a strip of celluloid* upon which gelatin* has been evenly spread and in every part of which a silver salt, usually silver bromid, has been suspended. This plate is placed at the focus of the lens of a light-proof camera (a camera obscura), and when the object to be photographed has been properly placed, the shutter opens for, it may be, a small fraction

Eastman Kodak Company

FIG. 167. The negative from which the positive shown in Figure 168 was made. The negative is dark where the object was light and light where the object was dark.

of a second. What happens at this point has been illustrated in Exercises 5 and 6 of this chapter; the light from the object is reflected into the camera and falls upon the sensitive gelatin film on the plate. Where the light strikes the film a change is produced in the silver salts, but this change cannot be observed by the eye.

The next step is taken in the dark room under a red light, when the picture is developed. This is accomplished by the use of a reducing agent (page 103), such as pyrogallic acid or hydroquinone. These chemicals act on the silver salts that were affected by the light, reducing them to metallic silver. Since the action of the light is greater upon those parts that have received the stronger light and less upon those parts that have received less of the light, the reduced silver is left upon the plate exactly in proportion to the intensity of the light that fell upon it. In other words, there will be larger amounts of free silver in the parts of the film that were exposed to a strong light, and smaller amounts in the parts exposed to a weak light.

The next step is the fixing of the plate. This is done by the use of " hypo " (sodium hyposulfite), which dissolves out the silver salt not acted on by the light and the developer, but leaves the free silver in the film. This makes the plate light where it was not acted on by the light, and dark where the light and the developer have acted on the silver so as to keep it on the plate. After fixing, the plate is thoroughly washed in water to remove the " hypo," and, when dried, the negative is ready for use. If you have carefully followed the process to this point, you will clearly see why it is called a " negative." The plate is dark where the object was light and light where the object was dark.

Eastman Kodak Company

FIG. 168. We go into the forests and fields with the camera to learn and carry home the secrets of the wild life to be found there.

The positive. The photograph is called the "positive." The process of making it on a " printing out " paper is as follows: A paper coated with egg albumen in which silver chlorid has been suspended is prepared as in Exercise 6. The negative is then placed over this paper and exposed to the light, which causes the paper

to turn dark. The action of the light is in proportion to the thickness of the silver deposit in the different parts of the plate — the paper becomes dark where the negative is light, and prints light where the negative is dark, in which respect it is like the original object from which the picture was made. After a proper exposure, the print is carried through the fixing process in the same way that the negative was. The color of the picture may be improved by toning the print in a solution of gold chlorid. After this the picture is washed, dried, and mounted in an album or upon a suitable card.

When a developing paper is used, the process of making a print is the same as that of making a negative. After exposure to the light the paper is developed, fixed, washed, and dried.

The present an age of photography. One member of nearly every family is almost certain to possess a camera of some kind or other, and "snapshots" are taken of the children and friends in their familiar surroundings. These pictures should be, and are, carefully preserved for the great value they will have in future years. The camera is taken on our picnics and other excursions to catch and preserve the beauties of natural scenery and to enable us to recall pleasant incidents in our lives. We go into the forests and fields, not with a gun as formerly, but with a camera, to learn and carry home the secrets of the wild life to be found there. We point the camera at the stars and from the photographs thus obtained are able to learn many facts we could not glimpse through the tele-

scope. We photograph the sun or the moon, an eclipse or a comet, or capture a stroke of lightning on a kodak film.

The art of photography has many valuable extensions into industrial and commercial life. The architect makes copies of his plans by the "blueprint" method of photography. He makes successive photographs of a building that is being erected to show the progress which the contractor is making in his work. By the various processes of photo-engraving,* pictures are reproduced for newspapers and books so that photographs of all the world are laid before our eyes, and the works of great painters are reproduced so that every touch of the brush is clearly seen in the copy. Color photography is now possible; and X-ray photographs are made, showing the bones and other internal parts of the human body.

The crowning achievement in the science and art of photography is the motion picture. This is made by taking repeated pictures of people and animals in action or of automobiles or other objects in motion, and then by the use of proper projecting apparatus reproducing these actions and scenes exactly as they occurred in the first place. This has been made possible by the manufacture of very sensitive films and the invention of a shutter by which an exposure of from $\frac{1}{100}$ to $\frac{1}{1000}$ of a second may be made.

CHAPTER TWENTY-NINE

THE LIGHT

In the last chapter we learned about the art of photography, and how light is made to paint the most marvelous pictures for our enjoyment and use. Our attention was given to the picture, however, and we took little thought of the light which does the work. In this chapter we shall study the light itself. We have already learned that it is the source of heat (page 251) and that it produces chemical action (page 275), but what we have not yet asked is, What is light and how does it produce these effects? Let us see what can be found out about this highly interesting subject.

The nature of light. Light does not seem to be matter; as far as we know it has no weight, and it leaps across space and passes through glass and other materials in a way that we should not expect matter to do. Does it not seem more like sound, which is waves of motion in the air, and is it possible that light also is waves in the air? We can answer this question by observing experiments that have already been performed for us.

Light comes to us from the sun. How many miles is it to the sun? How high does the atmosphere extend above the surface of the earth? Is there air all the way from the sun to the earth through which a wave could travel to us?

An incandescent electric-light globe has had practically all the air pumped out of it. Look through such a globe at some object. Does the light pass through it? Is the light able to travel out from the luminous filament to

the walls of the lamp? Could it do this if it depended upon the air? Review the exercises on page 237, and find the proof that light cannot be waves in the air.

A simple and satisfactory explanation of the nature of light has not been easy to find, but scientists believe that all space, even the spaces among the molecules of bodies of matter, is filled with an invisible substance which they have called ether, and that light is waves in the ether that can be recognized by the eye. When these waves dash against the retina of the eye, they start impulses to the brain that give us the sensation of light. When they strike the photographic plate, they break down and change the silver-bromid molecules in the plate; and if with a lens a great number of these little waves are all turned toward one point on a piece of paper, they beat upon it until the paper takes fire (page 251).

Light travels at the tremendous velocity of 186,300 miles per second. It comes from the sun to the earth in about 8 minutes, and it would take only one seventh of a second to go around the earth.

Light and motion. Sir William Crookes, the eminent English scientist, invented an interesting piece of apparatus known as the radiometer.* It consists of a framework which is so nicely poised that it rotates with the greatest freedom. It is inclosed in a glass bulb from which practically all the air has been removed. When exposed to the sunlight, the little mill begins to rotate. The more intense the light and heat the faster it whirls about. Motion is produced by the light. We

FIG. 169. A radiometer.

shall come back to this experiment as we study a later chapter.

Reflection of light. At this point we need an experiment which almost every boy has tried before, for the purpose of having a bit of fun or playing a trick upon some one. We may still have fun with it if we put it to a more scientific purpose.

Exercise 1. Hold a small mirror in the path of a ray of sunlight and notice the direction from which the ray has come and also the direction it takes after it leaves the mirror. This is best done in the dark room.

What you have observed is an example of the reflection* of light. The light waves strike the mirror and rebound, or are thrown back, as a ball bounds back when it is thrown obliquely upon the ground or sidewalk. The ray of light coming to the mirror is called the incident ray, and the ray leaving it the reflected ray.

Exercise 2. Place your lead pencil on the spot where the ray of light strikes the mirror and make the pencil perpendicular to the mirror at that point. Notice that the incident and reflected rays are on opposite sides of the perpendicular. Perhaps you will be able to satisfy yourself that the angle* which the incident ray makes with the perpendicular is exactly equal to the angle which the reflected ray makes with the perpendicular.

FIG. 170. The angle of incidence is equal to the angle of reflection.

The above experiment can be better performed by laying a mirror on the floor in a dark room and using light from a small opening or from a lighted candle. Figure 170 will show you what you may observe if you make the experiment in this way. The line *PB* is perpendicular to the mirror at the point of incidence *B*. The angle of incidence is the angle *IBP*, and the angle of reflection is the angle *PBR*. These two angles are equal, and the law holds good whenever the reflecting surface is perfectly polished. The law of the reflection of light is that the angle of incidence is equal to the angle of reflection.

Exercise 3. Look into a mirror and note the image of some object other than yourself. Without changing your position or looking around, see if you can accurately locate the position of the object itself. Do not look at the object until you have described its position, in words, to your teacher or classmates.

Exercise 4. Examine your own image* in a mirror. Are the right and left sides reversed? Get your answer by thinking on which side your right and left hands would be if you turned round and faced the same way that the image is facing.

Exercise 5. Look again at your image in a mirror. Note that it seems to be exactly as far behind the mirror as you are in front of the mirror. Advance toward the mirror and

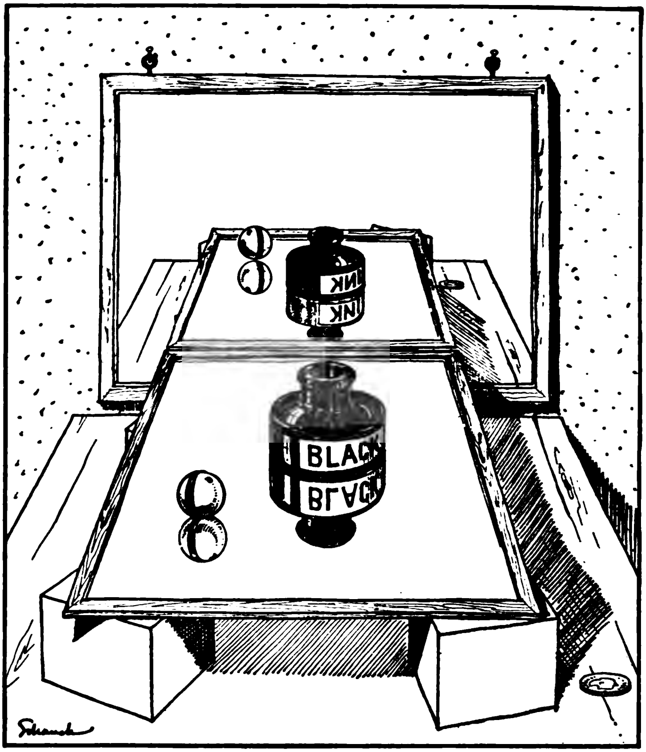


FIG. 171. The image appears to be as far behind the mirror as the object is in front of it.

walk backward from it. Does your image seem to advance and retreat in the same way?

A second important law in the reflection of light is that the image appears to be as far behind the mirror as the object is in front of it.

Exercise 6. Lay the mirror on the table, in a room that is not darkened, and place upon it a glass of water or other

object. Notice that the glass seems to stand upon another one that is bottom side up. Notice that every point in the image seems to be just as far behind the mirror as the corresponding point of the object is in front of it, and also that the image is of the same size as the object. From the principle that we learned in the last experiment, can you explain why the image is wrong side up?

An enjoyable scientific game. These two principles (what are they?) of the reflection of light, if you learn to recognize them, will lead to endless enjoyment as you notice the curious antics played by the light wherever there are bright reflecting surfaces, such as plate-glass windows, mirrors in hotels and restaurants, polished metal or wood on boats and cars, and the liquid mirrors that nature has provided in the great out-of-doors. Make it a part of the pleasure of your ride on the cars to trace out the place of the objects which form the images you see; such a study will make even more beautiful the inverted landscapes buried deep in the heart of pond or pool.

FIG. 172. The stick appears to be bent where it emerges from the water.

Refraction* of light. We are now to deal with a new word and the idea for which it stands. Begin with a visit to the dictionary.

FIG. 173. When the vessel is filled with water, the coin comes into view.

Exercise 7. Thrust a stick obliquely into a pail of water. The stick appears bent. Is it bent? Be sure sometime to visit a river, lake, or pond, and perform the same experiment under much more favorable conditions.

If you have had any experience with water, you know that it is difficult to tell exactly where an object is when it is under water. Only an experienced person can spear a fish, and a pond is always deeper than it looks. Does something happen to the light as it comes from beneath the water to our eyes? Let us try some other experiments.

Exercise 8. Look obliquely into a pail of water and then place your finger on the outside of the pail where the bottom seems to be. What mistake did you make? Why is water always deeper than it seems to be?

Exercise 9. Take a deep dish which is empty and place a bright coin on the bottom. Take your stand so that you can just see the farther edge of the coin over the edge of the dish. Now, keeping your eye at the same place, have some one fill the dish with water. You will see the coin gradually brought into full view.

The coin seems to have moved in the water, but this is not the case. A diagram will explain what has happened (Fig. 173). The ray of light from the coin *A* passed in a straight line to *D*; but when the dish was filled with water the ray was bent, or refracted, as it left the water

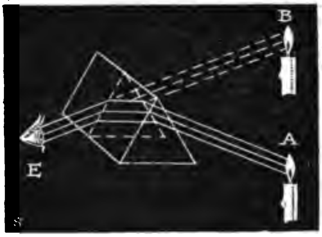


FIG. 174.

at *E* and passed into the eye at *C*. As the eye seems to see an object in a straight line with the ray that enters the eye, it seemed in this case to see the coin at *B*. Hence the bending of the rays of light as they pass out of the water causes the coin to seem to be more elevated than it really is and to seem to be moved toward the farther side of the dish.

This bending of the ray of light is called refraction. It occurs when light passes from one substance, or medium, into another of different density, as from water to air or from air to water. You will learn more about refraction when you go further in your study of physics.

Refraction of light by glass. Many substances besides water refract light, a fact which can be well shown with a triangular glass prism.* One that is 6 inches long and has faces that are $1\frac{1}{8}$ inches wide will cost about 40 cents. A substitute may be found in a pendant from a glass chandelier, or a cut-glass bottle stopper of 3 or 6 sides. As you work with the prism you may notice a play of colors in the light that passes through it. The study of this will be deferred until near the end of the chapter.

Exercise 10. Taking the prism in both hands, hold it before your eyes so that the lower face is horizontal or level with the floor. In this position look through it into the eyes of another person so that you see them clearly.

When you have established the proper position for the prism, you can study the path of the ray of light which passes from your friend's eye through the prism and then on to your eye. You may have to practice with the prism some time before you succeed with this experiment.

If the prism were not in the way, the path of the light would be perfectly straight; for, as you have learned, light travels in straight lines through the air. Here, however, its path is in two media,* the air and the glass. On this account it is bent from its path, just as it is bent when it passes from water to air or from air to water. Figure 174 will help you to understand what has happened. The rays of light from *A* strike the prism at *I*, but instead of going on in a straight line, they are bent both when they enter and when they leave the prism. Since light usually comes to the eye in a straight line, the mind judges that it has done so in this case also. The candle therefore appears to be at *B*. Copy Figure 174 on the blackboard and explain it to the class.

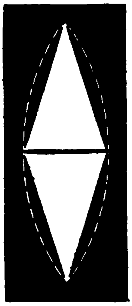


FIG. 175. Diagram to show how a lens convex on each side resembles two prisms with their bases placed together.

A study of the reading glass. Borrow the large reading glass from Grandmother, or use the one that may be furnished from the physics laboratory. It should be convex on both sides.

Exercise 11. Repeat Exercise 16 on page 250. Note that all the rays of light are bent inward so that they fall on one spot upon the paper. This spot is called the focus of the glass.

FIG. 176. The image formed by the lens is upside down.

Why does the glass turn all the rays of light inward? If we go back to the triangular prism for a brief review, we may find a partial explanation of the focus of the reading glass. As we traced the path of the ray of light through the prism, we noticed that the bending of the ray was in both cases in a direction toward the base of the prism. This being so, let us ask ourselves what would happen if two such triangular prisms were placed with their bases together. Is it not clear that all the rays of light from a given point of the object which falls upon both prisms would be gathered together at a focus on the other side? Figures 174 and 175 will help you to understand the resemblance between the lens of a reading glass and two prisms placed base to base.

Exercise 12. Throw an image of a burning candle on a white wall or on a piece of white cardboard in the manner shown in Figure 176. Is the image upside down? Notice that the lens will form a clear image when it is held in only one place.

How images are formed by lenses. How does a lens form an image? Visit a motion-picture theater or at-

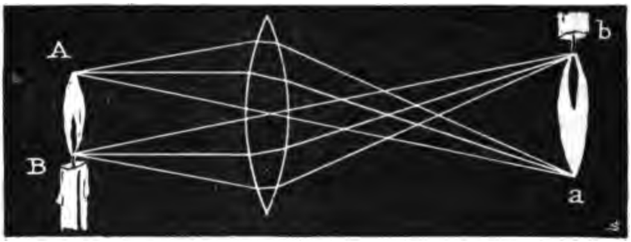


FIG. 177. Diagram showing how an image is formed by a lens.

tend a stereopticon exhibition and see if you can study out this problem. As you well know, there are no real pictures, but only images, on the screen. These are formed by placing the films or slides in front of a strong light and then allowing the light to pass through a convex lens to the screen. All the light which shines through one point of the film is focused in one point on the screen, so that the complete image on the screen is made up of an innumerable number of images of all the different parts of the film. Thus all the rays from a tiny flower in the film are brought together to make a flower on the screen, the rays from each twig and leaf on a tree are focused in their own place to form an image of the tree, and the light from the eyes, nose, mouth, cheeks, chin, forehead, and hair of each actor is brought together in such a way as to build up an image of the face.

If the explanation given above is not clear, examine Figure 177 and note how all the rays of light from one point are brought together in one point to form an image. Then imagine the film in the motion-picture machine to be composed of thousands of separate points and that

an image of each is being formed, and you will have the key to the explanation you are seeking. Is the film inserted in a motion-picture machine upside down? If so, why is this necessary?

Magnifying glasses. The pictures on a motion-picture machine are not more than an inch in diameter. The image on the screen may be 10 feet across. Clearly it is possible by means of lenses to make objects appear much larger than they really are.

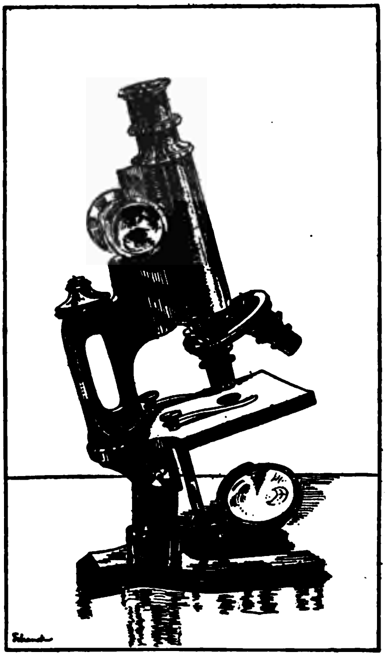


FIG. 178. A microscope.

Exercise 13. Hold a reading glass over the page of your book. At first you may see nothing. Hold the glass close to the print with your eyes at some distance from the glass. Then gradually move the glass away from the page and closer to your eye. Notice that the glass magnifies the letters and makes them appear nearer to the eye.

Microscopes* and telescopes.* First of all, learn to appreciate the literal meaning of these words. Your

unabridged dictionary will tell you that the Greek word *micro* means "small"; that the word *tele* means "far" or "far off"; and that *skopein* means "to look at." What do the two words at the head of this paragraph mean?

Microscopes and telescopes are made by placing several lenses, similar to the one you have examined, in such a relation to each other that very great magnifying power is produced. Sometime when you have a chance to look through a great telescope you will see how it seems to bring the moon or other distant object very much nearer. A pair of opera glasses will help you to understand this. The best microscopes magnify about two thousand diameters and bring into view hundreds of interesting objects that are wholly invisible to the naked eye. How tall should you appear if you were viewed through such a microscope? It will be a very useful exercise to spend some time in becoming familiar with the many wonders to be revealed by the microscope.

The human eye. The most wonderful of all optical* instruments is the human eye. In front it has a transparent window called the cornea, and behind the cornea a crystalline lens, which focuses the rays of light and forms images of the objects that we see on the retina. In the retina are the ends of the fibers of the optic nerve; when images fall on the retina the nerve fibers are stimulated and messages started to the brain. When these reach the brain they cause the sensation of sight and give us information about the objects that we see. It is a curious fact that only light waves can cause the eye

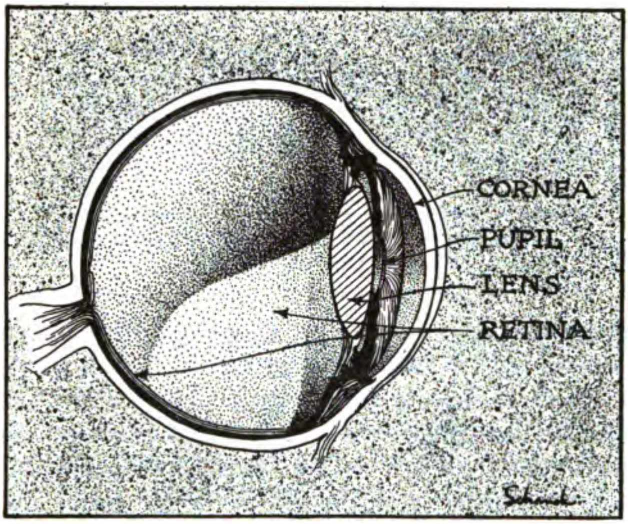


FIG. 179. A section through the eye.

to see, and that only through the two eyes can the light make its impression on that most wonderful mechanism, the human brain.

Spectacles. In Exercise 12 you found that a clear image was formed only when the lens was at a certain point. The image in the eye is clear only when the retina is at a certain distance behind the lens, and some eyes are too long or too short for clear sight. Sometimes the difficulty is that the rays of light cross before they get to the retina; sometimes they have not yet come to a focus when the retina is reached. In either case, the image is blurred and sight is indistinct.

The remedy for these and certain other troubles is

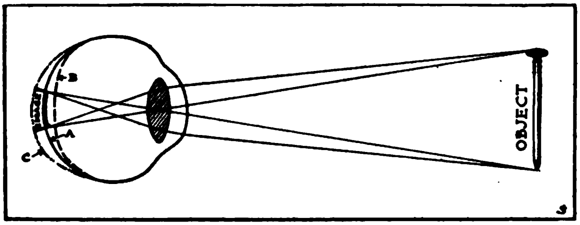


FIG. 180. Diagram showing the shape of a normal eye (A), a far-sighted eye (B), and a near-sighted eye (C).

to put spectacles in front of the eyes that will help focus the rays of light so that the image will be formed exactly on the retina. Figure 181 shows the kind of lens that is used on far-sighted eyes. Other kinds of lenses must be used when the eye is too long or when there are other defects in the shape of the eye or in the lens. Eyes that need glasses should be fitted with them; for many persons suffer from headaches, nausea, and nervous troubles because the sight is not clear or because the eyes are being strained to make it clear. Only a skilled eye specialist should attempt to fit glasses; it is a delicate task to adjust them so as to correct exactly all the defects that may be in a pair of eyes.

The solar spectrum. We have now to study one of the most wonderful and interesting facts about light.

Exercise 14. Take the prism to the dark room and place it in the path of a beam of sunlight from the outside. Hold a white cardboard beyond the prism or allow the light to strike the white wall of the room. We shall find that the ray not only is bent from its course, but that it is wonderfully broken up into a number of bright bands of color, the

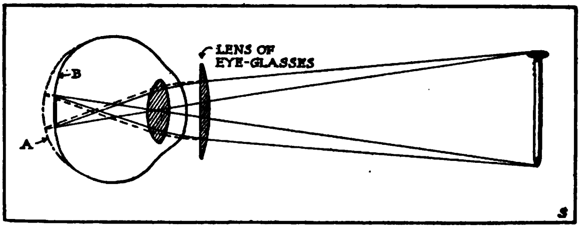


FIG. 181. Diagram showing how glasses bring the rays of light to a focus on the retina of a far-sighted eye. The dotted line represents the path the rays would have taken if they had not been bent by the lens.

colors of the solar spectrum.* These colors are red, orange, yellow, green, blue, and violet.

What is the explanation of this curious change which the prism has produced upon the light? Simply this: light waves are of different lengths. The red waves are the longest and the orange next longest; then come the yellow, green, and blue in the order of length, and last the violet waves, which are the shortest of all. In passing through the prism the shorter waves are refracted, or bent, more than the longer waves; thus the violet rays are refracted the most and the red the least. You will see that because of this fact the different waves that pass through the prism fall on the wall or the cardboard in different places and thus the colors are separated. This is called dispersion of light.

The rainbow. We will close our present work on light with a study of that beautiful object, the rainbow. A number of facts are to be observed.

Exercise 15. This is an exercise which can be carried out only at certain times, for the sun must be shining and

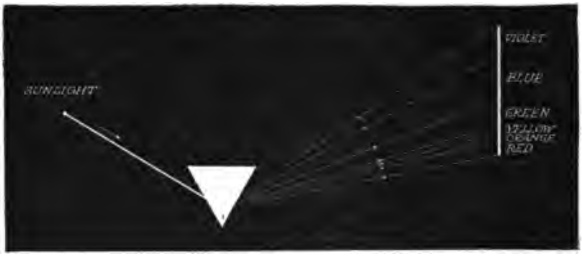


Fig. 182. Diagram illustrating the dispersion of light by the prism. The short violet waves are refracted most and the long red waves least.

the rain falling at the same time. At what time of day will the rainbow be in the east? When in the west? Can you face the sun and see the rainbow at the same time? Is the bow a part of a perfect circle?

What two colors are the most prominent in the bow? Which of these is on the inside? Which is on the outside? Can you detect the other colors of the solar spectrum lying between these two?

Here is a clear case of the dispersion of light into its prismatic colors. Now recall the method of causing this dispersion, as you have learned it. What acts as the prism in this case? A drop of water disperses the light; in fact, every drop of water that is falling acts as a refracting prism. A ray of light enters the drop and is refracted, striking the inside surface of the drop on the opposite side. It is reflected back upon its course, and as it passes out of the drop is again refracted. Thus the colors are separated from each other. Each drop will form a perfect spectrum, but only one of the colors may come to the eye of the observer; other drops will send the other colors, until a perfect bow is produced.

Sometimes a second larger rainbow, known as the secondary bow, is seen outside the primary bow. In this the colors are reversed, the violet being on the inside and the red on the outside.

Other facts about light. White is a mixture of all colors. Black is the absence of light. The page of your book is white because it reflects all kinds of light waves to your eyes. The letters on the page are black because they absorb all the waves and send nothing to your eyes. A red light appears red because the glass allows the red waves to pass through and stops the other waves. The grass is green because it reflects the green waves and absorbs the other waves that come to it from the sun. In the lights and shadows that play about you; in the colors of flames and of the stars; in the light that shines through stained windows and colored lamps; in the colors of sky and water and of fruits and flowers; and in the tints found in books and pictures, material for a hundred lessons is at hand. Each day experiments will perform themselves for you; with no effort on your part the results will leap into your eyes. Is your brain asleep, or is it alive to all that comes to it through the windows of the mind?

CHAPTER THIRTY

THE MARINER'S COMPASS

"AND when neither sun nor stars appeared for many days, all hope that we should be saved was lost." So Luke, the companion of Paul, wrote of the time when they were overtaken by a storm at sea, and his words picture to us the terror that the sailors of those days had of being lost upon the deep. They steered their course by observations on the sun and stars, and when these were hidden by clouds all sense of direction was gone and the helmsman was as likely to steer the ship toward the rocks of a hostile coast as toward a safe port.

FIG. 183. A common form of compass. The card is turned about until the symbol for north is under the point of the needle. The other directions can then easily be determined.

Now all this has changed, and men strike out boldly across the vast expanse of the ocean; for they carry with them an instrument known as the compass, which through fair weather and foul points to the north and thus enables them to know the direction of their course.

The compass. The compass was introduced into Europe about the twelfth century and has long been used by mariners, surveyors, travelers, and others. The essential parts of it are a delicately poised magnetic needle, and a compass card on which are marked the "points of the compass." The needle is free to turn in any direction and always points approximately to the

north. In the larger compasses the card is attached to the needle and turns with it, but in small compasses the card is under the needle and must be turned by hand. The needle and the point marked north on the card will always point toward the north, and from this the actual direction in which the ship or the person is going may easily be determined. The card is divided into 32 equal parts by lines drawn from the center, each part containing 11° 15′. How many degrees are there in a complete circle? Study the system of names on the card that indicates direction (Fig. 183). A small compass may be purchased at a jeweler's at a low cost.

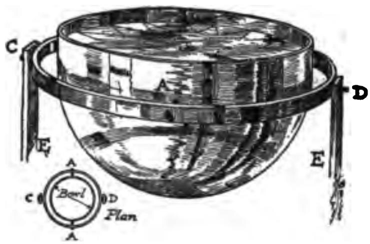
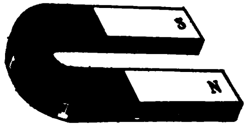


FIG. 184. A mariner's compass.

The mariner's compass. For use upon ships, one addition must be made to the common compass. In order that the needle may always be in a horizontal position and be free from jarring caused by the tramp of the sailors and the motion of the ship, the box is suspended in the gimbals, as is shown in Figure 184. The bowl is hung by two pivots (*A*) on the opposite sides of a brass ring (*C*, *D*) which surrounds it. The brass ring is itself balanced on two pivots on upright supports (*E*, *E*). It will be seen that whatever position the supports are in, the box maintains its upright position. Study Figure 184 and make sure that you understand why this is the case.

Exercise 1. Bring a piece of steel, as a bunch of keys or a hammer, near the needle of the compass and note how



FIGS. 185 and 186. A bar magnet and a horseshoe magnet.

the needle of the compass is disturbed. This will show you why surveyors and navigators* are careful to keep all forms of iron away from the compass.

The lodestone. At an early date, people living near a city of Asia Minor noticed that a certain kind of iron ore possessed the power to attract small pieces of iron. They named this ore magnetite* after the name of their city. Beds of magnetite are found in the Adirondack Mountains of New York and in Pennsylvania, Virginia, and North Carolina. Deposits of magnetite are known also in Minnesota, Colorado, Utah, and California.

A common name for magnetite is lodestone, or leading stone. If a piece of it is hung by a string, it will swing about until it indicates north and south. This fact was discovered very early, and the needles of the early compasses were made of this material. A piece of magnetite may be purchased for a small sum from a dealer in laboratory supplies.

Magnets. The name "magnet" is used for anything that will attract iron. Magnetite is a natural magnet. Pieces of iron and steel may be changed into

artificial magnets by stroking them with a natural magnet, and, as we shall see in the next chapter, much stronger magnets may be made by passing an electric current around a piece of steel.

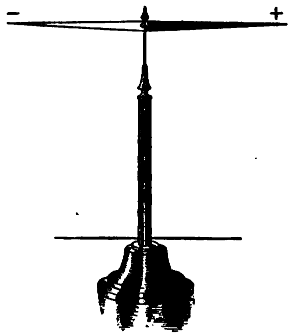


FIG. 187. A convenient form of magnetic needle for laboratory use.

Exercise 2. First, try to see whether your knife blade will attract small tacks or other pieces of iron. Then draw it several times, in the same direction, over a piece of magnetite and repeat the trial with the tacks.

Some magnets are straight and are known as bar magnets (Fig. 185). Some are U-shaped and are called horseshoe magnets (Fig. 186). The needle of a compass is a light bar magnet. A convenient form of a magnetic needle for laboratory use is shown in Figure 187.

Exercise 3. Take the needle from its support, hold it in your hand, and present either end to some iron filings or tacks. Does either end of the needle attract iron? The same experiment may be performed with a bar magnet.

Place the needle back on its support and bring a piece of iron near either end. Does the iron also attract the needle at both ends? A bar magnet, suspended as shown in Figure 190, may be used in this experiment if a suitable compass needle is not at hand.

This experiment shows that a magnet not only attracts iron, but is also attracted by iron.

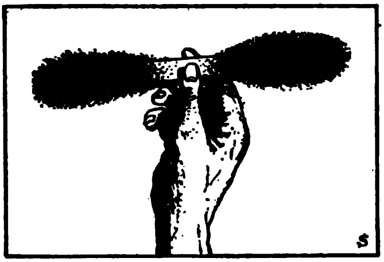


FIG. 188. The iron filings are attracted most strongly by the poles of the magnet.

The poles of a magnet. The ends of a magnet are called its poles. One of these poles is called the positive or north pole, and the other the negative or south pole.

Exercise 4. Lay a bar magnet in some iron filings. What part of the magnet attracts the filings most strongly?

The force by which the iron is drawn to the magnet is known as magnetic force. In Exercise 3 we proved that this force not only draws the iron to the magnet but also draws the magnet to the iron.

Exercise 5. Lay a piece of stiff paper over the magnet and sprinkle iron filings on the paper. The iron does not touch the magnet, but it is affected by it because it has come into the magnetic field. Notice that the filings tend to collect in lines.

The lines along which the filings tend to arrange themselves are called lines of magnetic intensity.

Induction. Induction is the process of producing or developing magnetism in a piece of iron or steel by bringing it near a magnet.

Exercise 6. Magnetize a knitting needle by drawing it across the pole of a bar magnet. Place the magnetized needle upon a small cork which is floating upon the water, or better, suspend it in the air by a small loop of paper and

string in such a way that it will be free to move. Notice whether the needle tends to point in any particular direction as it comes to rest.

The needle is magnetized by induction when it is stroked on the magnet, and, like the needle of a compass, points approximately north and south. A needle of this kind can be used to perform Exercise 3.

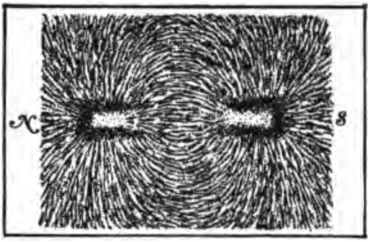


FIG. 189. The iron filings arrange themselves along the lines of magnetic force.

Exercise 7. With a bar magnet pick up a nail. Present the outer end of the nail to the end of another nail, repeating this several times. This is an illustration of what is called magnetic induction. The nail becomes a magnet when it is brought near the magnet and it is then able to magnetize and attract another nail.

It is an interesting fact that in magnetizing other pieces of iron a magnet does not lose any of its magnetism but rather gains more by the exercise.

The effect of one magnet on another magnet. We have found that either end of a magnet will attract unmagnetized iron. What effect does one magnet have on another?

Exercise 8. Present to either end of a magnetic needle (Fig. 187) or of a suspended bar magnet (Fig. 190) the north and south poles of a second bar magnet. What results do you get?

By this experiment it is easy to discover the important law that like poles repel and unlike poles attract each other. With a "dipping needle" and a long bar magnet, the same law can be proved in another way (Fig. 191). If the needle is moved toward the north pole of the magnet, the south pole of the needle will be drawn down toward the magnet, and when the needle reaches the north pole of the magnet it will stand in a perpendicular position. The reverse action will be produced by moving the needle toward the south pole of the magnet.

FIG. 190.

Why the compass points north and south. When a dipping needle is carried from the equator to the poles of the earth, the needle behaves exactly as it does when it is moved along a magnet. As the journey to the north is made, the end of the needle which points north turns more and more downward, and if the needle is moved southward exactly the opposite movement follows. Hence it is inferred that the earth is itself a great magnet, having its positive and its negative pole. The north, or negative, magnetic pole is northwest of Hudson Bay, about 20 degrees south of the geographical north pole. The south, or positive, magnetic pole of the earth is a point in the Antarctic Ocean at the end of a diameter drawn from the north magnetic pole through

the center of the earth. The ordinary magnetic needle, when it is permitted to swing freely, obeys the attrac-

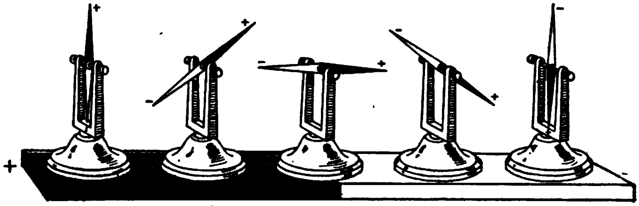


FIG. 191. Unlike poles attract, and like poles repel.

tion of the earth's magnetic poles, and all such magnets point to these poles. If a needle is located anywhere on the meridian of longitude passing through both the north pole of the earth and the north magnetic pole, it will point due north and south. This is the line which is called the line of no variation. It passes through central Ohio. At all places east of this line the needle points somewhat west of north; at places west of it, the needle points east of north.

Other uses of magnetism. The account of the mariner's compass and how it points the way across the trackless ocean or through the untraveled forest has shown us one great use of the magnet; but it has not brought to light a vastly greater service which the magnet renders. Without that form of magnet known as the electro-magnet, much of the work of the world could not be done. By its power we move railroad trains, street cars, and automobiles, set electric fans to whirling, and drive the wheels of great factories. How this is done will be explained in the next chapters.

CHAPTER THIRTY-ONE

ELECTRICITY

Great Western Power Company of California

FIG. 192. The Las Plumas hydroelectric plant on the north fork of the Feather River. The water is carried through a tunnel in the mountains and falls 465 feet through pipes leading down the mountain side to the power plant below. The capacity of the plant is 100,000 horse power, and the United States Government reports estimate that 550,000 horse power could be generated by the waters of this river.

THE Feather River rises in the high peaks of the Sierra Nevada Mountains in northern California and dashes down the western slopes of these mountains on its journey to the sea. The waters from the melting snow develop an enormous force as they plunge over huge bowlders and roar through narrow gorges to the valley far below. In ages past, this river washed from the rocks of the mountains large amounts of gold, which were found by the miners in the sands of its lower courses. Now its waters are performing a work much more important to mankind.

On one side of the north fork of the river stands a

hydroelectric* plant. To this plant the water falls 465 feet, and by its giant power it sets in motion the wheels of great dynamos. From the dynamos comes a wonderful something called electricity, which is carried by wires hung on steel towers or through submarine cables to many towns and cities, even to San Francisco, 160 miles away.

What is electricity? How can the falling waters of a river produce a stream of power that operates railroads, gold dredges, and mines, turns the wheels of factories, and lights houses and towns? What is the nature of this silent servant of mankind that cooks our food, rings our doorbells, explodes the gasoline in our automobiles, reproduces the human voice at the farther end of a slender wire which stretches across a continent, or projects a message through space across the vast expanse of an ocean? We live in the age of electricity. Let us see if we can learn something of it and of how it can be controlled.

Early history of electricity. Thales of Miletus,* one of the seven wise men of Greece, discovered that when amber* is rubbed with silk it gains the power to attract to itself light substances, such as bits of paper and fibers of cotton. The Greek word for amber is elektron, and from this our word electricity is derived.

The discovery of Thales did not produce any practical results for the world except to give us an interesting fact and a name. More than two thousand years passed by before any advance in the understanding of electricity was made. At last, toward the end of the

sixteenth century, Dr. Gilbert, a physician* to Queen Elizabeth, showed that the property which Thales had discovered amber to possess was not a property of that substance alone but was also to be found in wax, glass, sulfur, and many or all other bodies. We may repeat some of his experiments.

Exercise 1. Rub a stick of sealing wax with a flannel cloth and hold the wax near small shreds of paper, cotton, or lint. Bring the knuckles of the hand near the wax. A crackling sound may be heard, and if the experiment is performed in the dark, a small bright spark may sometimes be seen leaping across the space between the hand and the sealing wax.

Repeat this experiment, using a dry glass tube. A long, narrow lamp chimney will do if no other glass tube is at hand. Rub the glass with silk.

Exercise 2. Draw a piece of dry, warm wrapping paper quickly several times between the dry thumb and fingers, or under the arm. Then see if the paper will cling to the wall of the room.

Repeat experiments like the above with a variety of substances. For example, rub with the hand the back of a cat or dog that has become dry and warm by lying close to the fire; comb the hair with a rubber comb; or scuff the dry feet over a warm, dry rug, and then hold the hand near the gas.

In all these experiments electricity is produced by friction. When glass, sealing wax, woolen or silk cloth, or other bodies are thus excited, they are said to be electrified, or charged. The electricity on such a body is known as static electricity.

An interesting experiment. Many interesting experiments can be done with electrically charged bodies. We shall begin with one that shows how such a body can exert a force upon another body, without touching it.

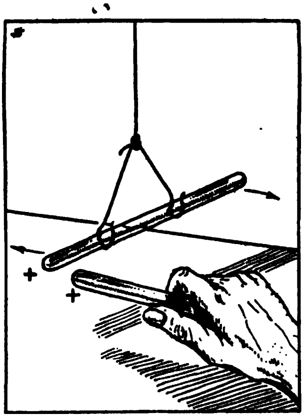


FIG. 193. Like kinds of electricity repel each other.

Exercise 3. Balance upon an egg placed in the top of an egg cup a ruler or a light, smooth lath 3 feet long or more. Rub a glass rod or a stick of sealing wax as before and present the electrified end to the end of the lath or ruler, but without touching it. The lath can be made to revolve on the egg. What happens when the excited rod is allowed to touch the lath?

Why does the excited rod drive the lath about? Here is a most interesting question for us to answer.

Two kinds of electricity. There are two kinds of electricity, positive and negative, just as there are positive and negative poles of a magnet. The charge of electricity upon the excited glass that has been rubbed with silk is said to be positive, and that upon the sealing wax that has been rubbed with flannel is called negative.

Exercise 4. (1) Suspend by a silk string a glass rod which has been rubbed with silk. Bring one end of another

FIG. 194. The pith ball is first attracted to the excited glass rod and then repelled.

electrified glass rod near the end of the one suspended. The latter is repelled.

(2) In the same way, suspend a stick of sealing wax which has been electrified by rubbing it with a woolen cloth, and bring near it the end of another electrified stick of sealing wax. The suspended stick is repelled as before.

(3) Now bring an electrified stick of sealing wax near to the suspended electrified glass rod. These will attract each other.

You are now ready to announce an important law; namely, like kinds of electricity repel and unlike kinds attract each other. Go back over your experiments and see that this is so.

How to detect electricity. Electricity can be easily detected by the use of an instrument known as an electroscope. A simple electroscope is shown in Figure 194. It is made by bending a glass tube or rod, supporting it in the cork of a bottle, and attaching to the rod with a silk thread a small ball made of pith from the inside of a dry cornstalk. Make at least two electroscopes of this kind.

Exercise 5. (1) Rub a dry glass tube or rod with silk and present it to the pith ball. Two things will happen to the pith ball: at first it will be attracted; but presently the ball will fly away, and then the excited glass will repel the ball.

(2) Repeat the same test with the sealing wax rubbed with the flannel. The pith ball is affected in exactly the same way.

The excited glass or wax causes the ball to become charged with electricity, and then the ball is repelled by the rod or wax. As a magnet will cause a nail or other piece of iron that is brought into contact with it to become magnetic, so a body that is electrically excited will electrify a second body that is brought near it.

The effect of negative and positive charges of electricity on each other. An important fact about electricity is that positive and negative charges will neutralize, or destroy, each other if they are brought together.

Exercise 6. Electrify two pith balls by touching one with an excited glass rod and the other with an electrified piece of wax. Then set the electroscopes so that the balls will be near each other. They will attract each other and come together. Do they lose their electric charges and fall apart after they touch each other?

When two bodies heavily charged with opposite kinds of electricity are brought near each other, the electricity may leap from one to the other through the air. Perhaps you may have noticed an electric spark in some of the experiments you have performed.

Lightning. A stroke of lightning is a charge of electricity which passes with terrific force from one cloud to another, or from a cloud to the earth, or from the earth to a cloud. The earth is charged with one kind of electricity and the cloud with the other kind,

FIG. 195. A great electric spark leaping across the space between a cloud and the earth.

and the lightning flash is a great electric spark leaping across between the two. No review of the electrical discoveries that have led to this remarkable age would be complete without mention of the man who proved that the lightning bolt and the electricity that we produce by rubbing a glass rod with a piece of silk are identical.

Benjamin Franklin. This celebrated man was not a scientist by profession, but a statesman* and writer. His mind, however, was always open to everything that could possibly add to the knowledge of the world. Being in Boston in 1746, he saw, for the first time, some experiments in electricity, and he was led to study the subject carefully. It occurred to him that the lightning of the clouds and the electricity that he had seen in the experiments were the same, and he planned an experiment to prove whether or not his ideas were correct. By the simple method of sending a silk kite with small metal points projecting from it high up toward the clouds in the

midst of a "thunder," or electrical, storm, he brought the electricity down from the clouds along the wet string of the kite. He caught a heavy charge of electricity in a bottle covered within and without with tinfoil, and by further experiments proved that this electricity was the same as that produced by friction.[1]

Electricity from chemical action. Volta, an Italian physicist who lived from 1745 to 1827, discovered that electricity may be produced by chemical action. This can be proved by a few experiments that are quite easily made.

Exercise 7. Fill a tumbler or beaker glass two thirds full of water and add a small amount of pure sulfuric acid. Immerse a strip of zinc in the liquid and notice the bubbles of gas which very quickly rise from the surface of the zinc. If a burning match be brought to the gas as it escapes from the surface of the liquid, a slight explosion will follow. This will show that hydrogen is being produced.

Exercise 8. Take the strip of zinc from the bath of sulfuric acid and, without drying or cleaning it, rub a few drops of mercury into it with a cloth. The surface will be coated over by a bright zinc-mercury amalgam. Place this amalgamated zinc back in the dilute sulfuric acid. Notice that little or no hydrogen is now given off.

Exercise 9. Remove the zinc and place a strip of copper

[1] The pupil will find further information about how a glass vessel is prepared to make it hold a charge of electricity in any text on physics in the discussion of the Leyden jar. However, no pupil should try to repeat Franklin's experiment. A Russian scientist lost his life by attempting to do so.

or platinum in the dilute sulfuric acid. No perceptible chemical action will be noticed; no hydrogen will be given off.

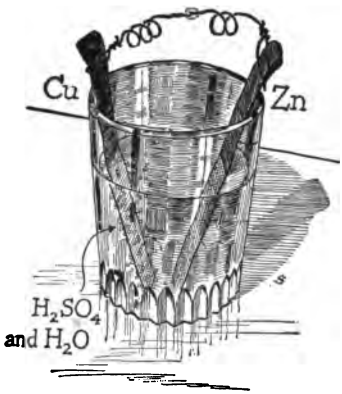


FIG. 196. When the wires are brought into contact, hydrogen is given off from the copper.

Exercise 10. Now place both the amalgamated zinc and the copper in the liquid and either allow the two pieces of metal to touch each other at the top or connect them by a wire from each. There will be a quick evolution* of gas. Notice that the gas is now coming from the copper and not from the zinc.

Now consider carefully the results of these experiments. Which of the two metals produced hydrogen when placed alone in the liquid? Which metal did not liberate hydrogen when placed alone in the acid? Recall the fact that it is only when the two metals are joined that hydrogen is evolved, and that then the hydrogen comes from the copper and not from the zinc. May we not conclude that bringing the metals together caused the hydrogen to be carried from the surface of the zinc to the surface of the copper, where it escaped into the air?

The voltaic cell. A piece of apparatus like the one we have arranged for our experiments is called a voltaic cell. By the chemical reaction within the cell, electricity is produced, and we speak of a current of elec-

tricity which passes through the liquid and carries the hydrogen from the zinc to the copper. The current passes from the copper into the connecting wires back to the zinc, thus forming a circuit. Joining the wires and thus connecting the two metals is called closing the circuit; separating them is breaking the circuit. Notice that these experiments have not furnished any proof that a current does actually flow, but it is plain to be seen that in this case chemical action has produced electricity, and it is convenient to speak of a current in the circuit.

Figure 196 shows a simple form of the voltaic cell. Any liquid that will act on the other two substances may be used in it; the one essential condition is that the chemical action of the liquid shall be greater on one of the substances than on the other. It will be seen that there is a wide range of substances that may be used for the construction of a voltaic cell, and many varieties of these cells have been made. A brief description of three forms of cells that are commonly used will be given to illustrate some of the different materials that may be used.

The gravity cell. This form (see Figure 197) is extensively used by the Western Union and other telegraph companies. Crystals of copper sulfate are placed in the bottom of the battery jar, which is then filled with water. A piece of copper is placed in the bottom of the cell, and a piece of zinc is suspended at the top. A few drops of sulfuric acid are added to the water. Both zinc and copper have wires leading from them out of the liquid.

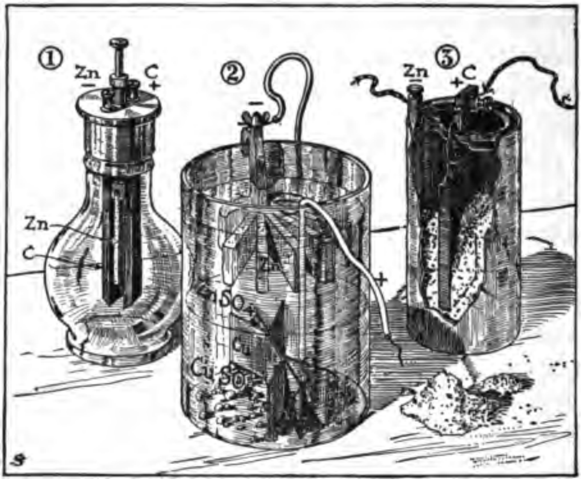


FIG. 197. Some common forms of electric cells. No. 1 is the Grenet cell, No. 2 is the gravity cell, and No. 3 the dry cell.

The Grenet cell. In this form strips of carbon and zinc are suspended in a solution of sodium dichromate and sulfuric acid. This combination furnishes a very energetic current for a short time and is much used for experimental work in schools. To stop the action of the chemicals on the zinc it should always be lifted out of the liquid after use. A good formula for the solution for this cell is: 30 parts sodium dichromate, 100 parts of water, and 23 parts of sulfuric acid, all by weight.

The dry cell. Dry cells are more extensively used than any other form, because of their low cost. They are not actually "dry" cells, as their name indicates. The zinc electrode* forms the outer wall of the cell, and within this is the positive electrode of carbon. Sur-

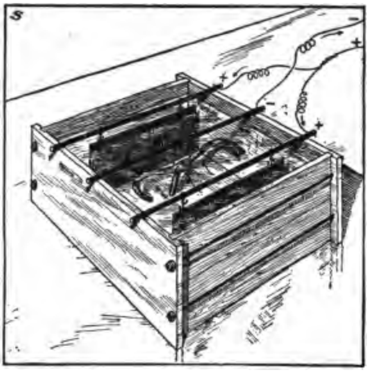


FIG. 198. Electroplating.

rounding the carbon is a moist paste consisting of a mixture of ammonium chlorid, zinc chlorid, zinc oxid, and plaster of Paris. The current is produced by the action of the ammonium chlorid upon the zinc. When the cell is new, it gives a strong current.

Terms used in connection with the electric cell. The solution used in an electric cell is called the electrolyte. The two metals, or the metal and carbon, used to produce the current are the electrodes. The electrode that is charged with positive electricity is called the positive electrode, or positive pole. The one that is negatively charged is the negative electrode, or negative pole. The copper or carbon is the positive electrode, and the zinc is the negative electrode. A battery may be a single electric cell, or it may be composed of a number of connected cells.

Electroplating. Many industrial and commercial uses are made of the electric current, and an interesting example of such a use is found in the process of electroplating. This is the process of depositing a thin coating of one metal upon the surface of another metal by the use of the electric current. Brass or iron, for ex-

ample, can be coated with nickel; or brass may be coated with gold or silver, as is done in the manufacture of cheap jewelry. The principle upon which this process depends may be understood from the following exercise:

Exercise 11. Attach to the two wires from an electric cell or battery two strips of lead or two silver coins for electrodes and place them in a solution of copper sulfate. After a little time it will be found that the negative electrode (the one connected with the zinc plate of the battery) will be coated with a thin layer of copper. The thickness of this layer will depend upon the time the process is allowed to continue.

If the solution in which the electrodes are immersed is a salt of silver, that metal will be deposited upon the negative electrode. In the same way, gold plating can be done by using a solution of gold in the "bath."

Conductors and insulators. A substance which permits electricity to pass through it easily is said to be a good conductor; a substance through which electricity passes with great difficulty is a bad conductor and is called an insulator. Copper is one of the best conductors known, and glass is one of the best insulators. If an electric current is to be brought from the central telephone office to your home, an iron or copper wire is used, while to prevent the current from passing from the wire to the poles on which the wire is hung, a glass insulator is used. When you go home today, be sure to notice this arrangement of telephone and telegraph wires.

Among good electrical conductors may be mentioned metals, charcoal, minerals, acids, impure water, vegetables, animals, linen, cotton. A list of good insulators would include dry air, shellac, amber, sulfur, wax, glass, silk, dry paper, rubber.* Which of these materials are used to cover electric wires?

Would it be wise to sit by an open window or stand in a doorway during a thunder shower when the wind was blowing the damp air into the house? Would you lean against a tree if you were standing under it during a thunder shower? Why cannot experiments with frictional electricity be conducted successfully unless the air be dry?

Resistance. There is no absolutely perfect conductor of electricity. All substances offer some resistance to the passage of the electric current, some more and some less. Wherever the electrical current finds resistance, heat is produced; for example, if a short piece of fine iron wire is made a part of the circuit of a voltaic battery, the wire will become heated, perhaps enough to melt it. Try this experiment.

The incandescent lamp. We may conduct a powerful current of electricity into houses with perfect safety, provided it is brought into the house over a thoroughly insulated copper wire. We can bring it to any point in a room that we may desire, — to the middle of the ceiling or over the study table. If then we cause the current to pass through a substance of high resistance, such as the fine wire of an incandescent bulb, intense heat and light will be produced. This is

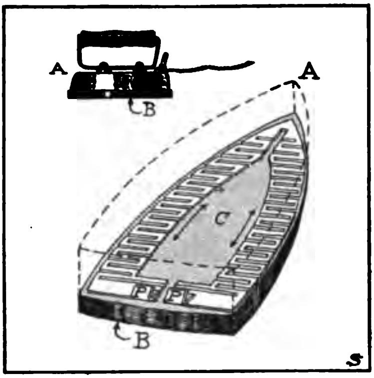


FIG. 199. The construction of an electric iron. Heat is produced by the current which passes from *P* to *P*. The layer of insulating material, *C*, keeps the current from passing into *B*.

illustrated in an incandescent electric light. You have noticed how very bright the slender filament or thread in such a lamp becomes. What is the Mazda lamp? Find your answer in some recent work on physics. Who is the inventor of this lamp? What other important inventions has he made?

The electric toaster. Study the construction of one of these modern household inventions and make your own explanation of it. Study and explain the electric flatiron, the electric footwarmer, and other appliances that illustrate the principle we have been studying.

CHAPTER THIRTY-TWO

ELECTRICITY (Continued)

In the last chapter we learned some facts about electricity, but our study has led us only to the threshold of this great subject. We shall in the present chapter learn further of how this mysterious "fluid" can be generated and controlled, but after the study is finished a hundred interesting experiments in electricity and many fascinating pages of reading matter on the subject will be left for the student who has the interest and the energy to make investigations for himself. To help you in any readings or experiments in electricity that you may undertake, a knowledge of the important principles of the subject is needed, and there is no better way to begin a study of these principles than by investigating the common electric bell.

The electric door bell. Figure 200 is a diagram showing how an electric bell is arranged. A wire leads out from one electrode of the battery to the bell, and another wire connects the bell with the other electrode, thus forming a circuit through the bell. At some point in the circuit a push button is inserted, and when the finger presses on the button the bell rings. Let us examine the different parts of this apparatus.

The wires. First of all, our attention is directed to the wires. They are of iron or copper, copper being much better than iron because it is a better conductor of electricity. Notice the insulation of the wires — the covering of silk or gutta-percha, or of cotton threads soaked in melted paraffin, that keeps the electricity from

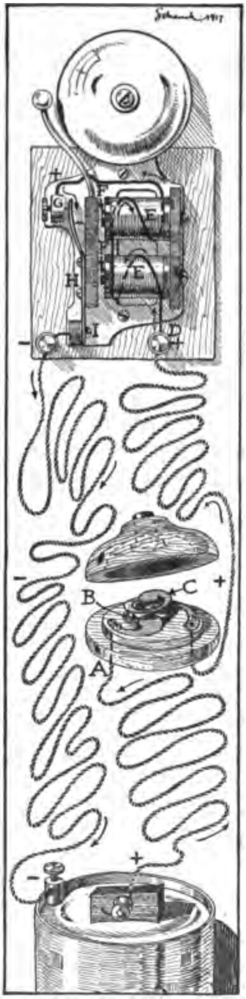


FIG. 200.

leaving the wires and flowing off into objects which the wires touch. The insulation is removed when the wires are to be joined to those of the battery, the push button, and the bell. Why? When an electrician is arranging an electric circuit, he carefully scrapes the ends of the wires so that they will be clean and bright. Why?

The push button. Figure 200 shows the structure of a push button. The current passes into the button at *A*, but from *B* to *C* there is a gap that the current cannot pass. When the button is pushed down, the point of it touches the spring *C*, and presses it down against *B*, and the gap is closed. The current then flows on through the bell and causes it to ring. When the finger is removed from the button, *C* rises so that the circuit is broken again and the flow of the current is stopped.

The bell. The current enters the bell at *D*, flows in the direction indicated by the arrows, and leaves through the wire at *I*. At *E* the wire is wrapped in coils around

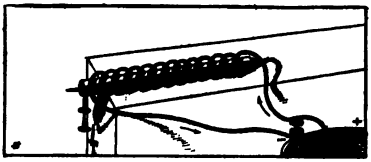


FIG. 201. The iron becomes magnetic when a current passes through the wire.

two rods of soft iron, *F*, and from *G* to *I* the current flows through *H*, which is an iron spring to which is attached the stem of the clapper of the bell. When the button is pushed and the current flows, the clapper vibrates rapidly back and forth, striking on the gong and causing the bell to ring.

Why the bell rings. How does the current flowing through the bell cause it to ring? This is a somewhat difficult question to answer, and before attempting to answer it we shall ask you to perform an experiment.

Exercise 1. Wrap a piece of insulated copper wire about a piece of soft iron. A bolt or large nail will do for the piece of iron, and the wire should be given 10 or 12 turns about it. Now connect the two ends of the wire to an electric cell. When the current begins to flow try to see if the iron will attract iron filings, a needle, or your knife blade. The iron has become magnetic. Break the circuit and notice that the iron loses its magnetic properties.

When the electric current flows through the bell, the rods of soft iron, *F*, become magnetic and draw to them the iron spring, *H*, thus causing the clapper to strike the bell. But when *H* is drawn away from *G*, a gap is made in the circuit and the current ceases to flow. The irons, *F*, then lose their magnetic property and the spring, *H*, leaves them and again makes the contact at

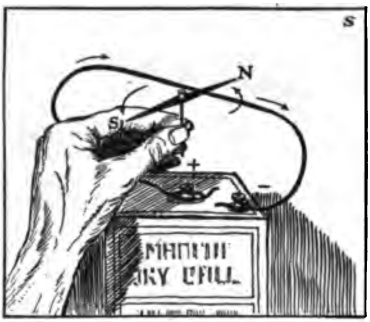


FIG. 202. The needle turns at right angles to the wire.

G. This again starts the current, and *F* again becomes magnetic and again causes the clapper to strike the bell. Thus the process of making and breaking the circuit at *G* is carried on very rapidly as long as the finger is kept on the push button, and the clapper moves back and forth, causing the bell to ring.

The electromagnet. Exercise 1 and the way the electric bell is made to ring suggest an interesting subject for study, the electromagnet. A few experiments will help us to understand how it is constructed and how it works.

Exercise 2. (1) Place a suspended magnetized needle or a compass under or over and parallel to an insulated wire through which an electric current is passing. The needle is affected. In what direction does it move?

(2) Make a small loop in the wire and hold it near the needle. Is the needle more strongly affected than it was by the single wire?

(3) Wrap the wire around a stick, making a coil of 10 or 12 turns, as was done in Exercise 1. Remove the stick and pass the current through the coil. Test again and note how much more strongly the needle is affected.

(4) Pass a short rod of soft iron through the coil, as in Exercise 1, and test again.

What we have learned. These experiments have brought to light some important facts. A current passing through a wire sets up a magnetic field around the wire. The wire becomes a magnet, the strength of which depends on the strength of the current flowing in it. As long as the current is passing through the wire it will turn the magnetic needle, just as the steel magnet turns it. The coil, or helix, is a more powerful magnet than a single wire; its strength depends on the number of turns of wire and upon the strength of the current. You have seen also that the strength of the coil magnet is greatly increased by the presence of the iron core. The iron intensifies the magnetic field.

The coil of wire with its iron core makes what is called an electromagnet. By using a great many turns of wire and a fairly strong current, magnets are produced that are much more powerful than the steel magnets which we have already studied. These electromagnets are frequently used on the great cranes employed in steel and iron mills and factories, for lifting heavy pieces of iron and steel. How is the magnet made to attach itself to the bar of iron or steel and to release it? Electromagnets are also used for separating iron from mixtures with other substances. How is the electromagnet used in a flouring mill?

Electromagnets are found in a great many electrical devices, such as the telegraph sounder, the telephone, and the electric bell, which we have studied. Examine electrical appliances to find electromagnets and note how they are used.

The galvanometer. The galvanometer is an instrument for detecting electric currents and for measuring their strength. Its essential part is a compass with a coil of wire wound about it. If this instrument is connected with the two wires from a battery or is introduced into an electric circuit, the electricity will flow through the coil of wire about the compass and cause the needle to be deflected. The stronger the current the greater will be the effect on the needle; by the effect on the needle the strength of the current can be measured.[1]

Making electricity do work. Electricity is made to run trolley cars and automobiles, to turn machines in factories, and to do many other kinds of work. This is accomplished by the use of electric motors. We cannot explain all the many complicated devices that give the modern electric motor its efficiency, but a simple experiment will show the principle on which it works.

Exercise 3. Suspend an electromagnet, such as was made in Exercise 1. The magnet will take a north and south direction as an ordinary magnet does; it has a north and a south pole. Present the north pole of an ordinary bar magnet to the north pole of the electromagnet. The electromagnet will be repelled and will turn away.

This principle is used in the revolving machine shown in Figure 203. A fixed and permanent horseshoe mag-

[1] In many galvanometers a heavy fixed magnet and a very light movable coil are used. In galvanometers of this type it is the coil and not the needle which moves when the galvanometer is introduced into an electric circuit.

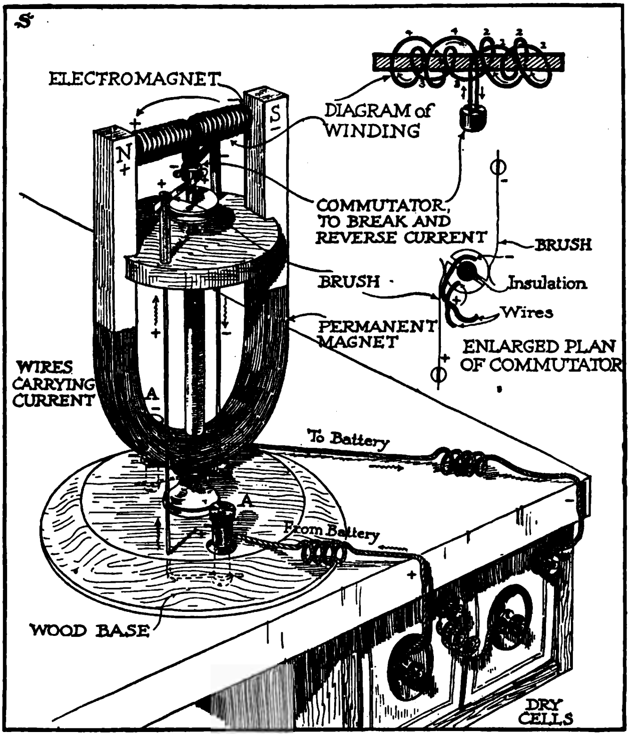


FIG. 203. The dynamo used as an electric motor.

net makes the sides of the machine, and an upright shaft capable of turning around is fixed in the axis of the magnet. To this shaft is fastened at right angles an electromagnet made by wrapping a piece of soft iron with a coil of insulated copper wire. The ends of the wire of the coil are fastened to the commutator. This is made of two metallic pieces that are attached to oppo-

site sides of the shaft so that they do not touch each other and are insulated from the shaft (Fig. 203). The current from a battery enters the machine by the binding posts (*A*, *A*) and passes to two springs ("brushes") that press upon the metallic pieces on the shaft and so complete the circuit.

When the machine is to be started, the electromagnet is so placed that poles of the same kind face each other. Thus the magnets repel each other, and the shaft begins to revolve. When the shaft has revolved a little more than one quarter of the way round (as in Figure 204), unlike poles begin to attract each other, thus causing the shaft to revolve through another quarter of the way. At this point each brush is pressing upon the opposite side of the commutator from that which it touched at first, and therefore the direction of the current in the electromagnet is reversed. This reversal of the current changes the poles of the magnet, so that now like poles of the two magnets are facing each other as at the beginning, and a second half-rotation is therefore begun as before.

This little machine is a simple electric motor, and the thousands of electric motors that are in use every day all operate on the same principle. When an electric fan whirls about, the force that runs it comes from the attraction and repulsion of two magnets for each other, and in the same way the shafts of great electric motors are made to revolve many hundreds of times a minute. By this method we are able to transform the energy of the electric current into motion, or mechanical energy, and by cog wheels, pulleys, and belts this motion may

be transferred to machinery as desired. The great advantage of the electric motor is that it enables us to employ the power where we want it. The force of the waters of a mountain stream can be used to generate electricity, and in a distant city the electricity can be made to do work.

Producing an electric current with a magnet. We have seen that electricity flowing in a wire creates a magnetic field about the wire. We are now to learn that a magnet can create an electric current in a wire.

Exercise 4. Fasten the two ends of a covered wire to a galvanometer, thus making a circuit. The galvanometer shows that the wire is carrying no current.

(1) Bring the wire near a magnet. A horseshoe magnet is the best to use. Quickly bring the wire near the pole of the magnet. The galvanometer needle is deflected,* showing that a current of electricity has been produced in the wire.[1]

(2) Make a coil of the wire and bring it quickly near the pole of the magnet. The needle is more strongly affected than before.

(3) Hold the coil still over the pole of the magnet. The needle of the galvanometer will gradually settle back to the zero point.

(4) Withdraw the coil quickly from the magnet. The needle is deflected again, but this time in an opposite direction.

(5) Bring the coil toward or take it away from the magnet slowly and then very rapidly. Notice that the more rapidly the coil is made to enter or leave the magnetic field, the stronger is the current that is produced in it.

[1] A sensitive galvanometer is needed to detect the current in a single wire.

Here we have found a third way to produce electricity, by bringing a wire or a coil of wire near a magnet and taking it away again. The current produced by the magnet is an induced current. It is produced only when the wire or coil moves, and its strength depends on the strength of the magnet and the rapidity with which the movement is made.[1]

Turn back, now, and read again page 304, and examine Figure 188, which shows the iron filings arranged along the lines of magnetic force. If a wire is forced through a magnetic field so as to cut the lines of magnetic force, a current is induced in the wire. Michael Faraday first discovered this fact, and it was one of the most important discoveries ever made by man. It enabled Faraday himself to make a machine that would generate electricity when it was whirled about, and from machines of this kind come nearly all the vast amounts of electrical energy that are used in our modern life.

The electric generator. In an electric generator the current is produced by revolving great coils of wire within the arms of a huge magnet, thus making the coils cut the lines of force in the magnetic field and producing an electric current that can be led off from the machine. In its operation the generator is exactly the reverse of the electric motor. In the motor the electricity is led

[1] It should be understood that the same results can be produced by moving a magnet near to and away from a stationary coil of wire. This statement may be tested by thrusting a magnet within a coil and withdrawing it.

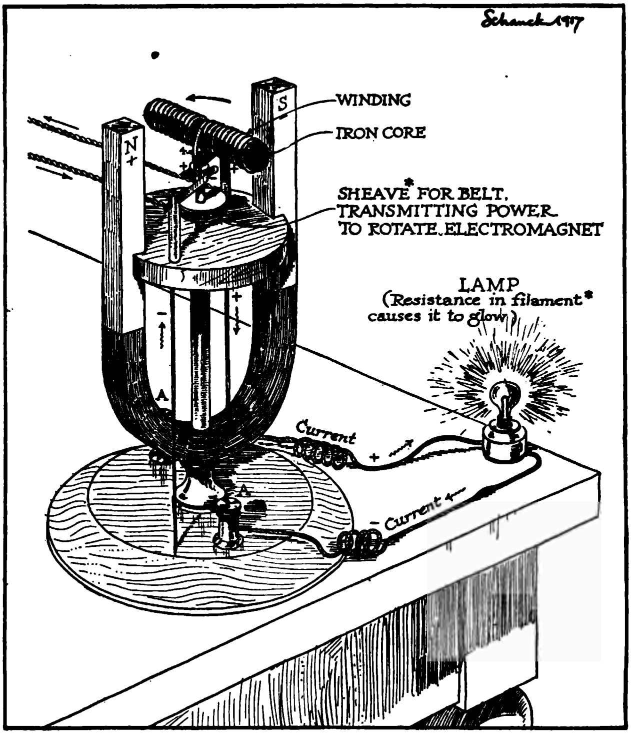


FIG. 204. The dynamo used as an electric generator.

into the machine. In the generator the electricity comes from the machine. In the motor the electricity is made to whirl the machine about. In the generator the shaft is driven about by water power or other power, thus whirling the "drum" through the magnetic field and generating the electricity.

The common electric generators, such as are used for

producing the current for electric lights, are made in the same way as an electric motor, but there are, of course, many details in the construction of the machines that cannot be described here. It will thus be seen that the electric motor and the electric generator are the same machine, the only difference in them being the way they are used. This machine is called a dynamo. In a strict sense either a motor or a generator is a dynamo, but usually a generator is meant when the term "dynamo" is used.

The importance of the dynamo. What does the word dynamo literally* mean? It is made from the Greek word *dynamis*, meaning "power." From this root we also get the words dynamics,* dynamite,* dynamometer,* and dyne.* All these words suggest the idea of power, and one of the best illustrations of immense power is found in the modern dynamo. In the construction of this machine our knowledge of many of the facts and principles of magnetism and electricity is utilized, and we are given a mechanism by which cheap forms of power can be transformed into electricity and by which the electricity, after it has been led to where it is to be used, can be transformed again into mechanical power for a thousand purposes.

It is probable that no machine ever made has meant more for the progress of man than the dynamo. Until recently nearly all the water power of our country went to waste, and even yet much of it is not being used in the work of man. We are impressed by the grandeur and sublimity of Niagara, Yosemite, or Kakabeka Falls,

but our minds must wonder at the vast number of horsepowers of energy that are every day lost in these and other falls. By means of the dynamo this water power can be transformed into electricity and made to turn the wheels of manufacture and commerce, thus lightening the labors of millions of persons in our land.

The wireless telegraph. We cannot here explain the details of how, by means of the wireless telegraph, messages are sent halfway round the earth, but it is fitting that this wonderful instrument should be mentioned before our study of electricity is closed. The essential part of the sending apparatus is a group of long, heavily charged wires (the antennæ) and a mechanism for causing surgings back and forth, or oscillations, of the electric charge in the wires. These oscillations cause waves to run out through the ether, "just as a stick laid on water and shaken up and down sends out ripples over the surface of the water." By suitable apparatus these ether waves are caught and the message is read perhaps hundreds or even thousands of miles from the point where it was sent.

Ether waves. No subject in all science is more fascinating than the ether vibrations which were mentioned in the chapter on light and which are the bearers of the telegraphic messages that can now be sent so swiftly and to such long distances through space. These waves are everywhere all about you, — racing in great numbers through your room, striking against your body, running through space in a medley of motion that almost passes belief, some of them even passing

through solid materials like glass and wood. The shortest of these waves are the X-rays; the longest are the electric waves used in wireless telegraphy, which are many yards in length. Longer than the X-rays are the waves of light, which the eye is attuned to receive; longer than the light vibrations are the heat waves, which in a former experiment (page 249) you felt beating against your hand. Already it is possible to telephone by means of ether waves, and some scientists look forward to the day when the energy that we need for heat and power and light will be sent where it is needed in the form of ether waves. About 342 million million horse power of energy is each minute sent in this way to the earth from the sun.

CHAPTER THIRTY-THREE

WORK AND ENERGY

The true scientist does not allow himself to become so busy with his hands that his mind becomes confused. There is no hurry in his work, and he often sits down quietly, far from his laboratory, to think over the meaning of the experiments that he has made. He does not try to use his apparatus in as many different ways as possible, nor does he aimlessly pile up masses of information on many different subjects; but he interprets his work as he carries it on and thinks over the conclusions that can be drawn from it.

In this chapter you will not be expected to perform any experiments, nor will you need your notebook to record your observations. We shall ask you to be a thinking scientist; most of the chapter will be a consideration of work that you have already done. The only piece of apparatus that you will need for these lessons will be your brain, and it is hoped that this machine will be in good condition; for the greatest difference between a good and a poor scientist lies, not in the hand, but in the mind.

Work. Whenever a force acts on anything to move it, change its motion, or check its motion, work is done. When you slide a box along the floor, you do work. When you run or when you throw a ball, even though it be done in play, you are doing work. When a bird flies, when an automobile moves, or when the brakes bring a moving train to a stop, force is exerted and work is accomplished. By work, then, we mean the effect

produced by the force, and where there is no effect, no work has been done.

Quantity of work. If a teamster is hired to haul a load of grain to market, he first takes note of the size of the load and then immediately wants to know how far it is to the place where it is to be delivered. His team will have to exert a certain force to haul the load, and it also makes a difference through what distance that force must act. The farmer knows that it requires twice as much work to plow two acres as it does to plow one. The horses exert the same force on the plow while doing the one piece of work as they do in the other, but they exert that force through twice the space. It would require the same amount of work to carry 1000 bricks up a ladder as to carry 500 bricks up two such ladders, or to carry 2000 bricks up a ladder one half as high.

The quantity of work, then, depends upon two factors, (1) the force exerted and (2) the distance or space through which the force acts; that is, the work done is equal to the force multiplied by the distance.

$$\text{Work} = \text{force} \times \text{distance}$$

Time and effort not factors in work. It will be noticed that in the laboratory of the scientist no account is taken of the time consumed in work. It takes the same amount of work to complete a given task, no matter whether it be done in ten minutes or in an hour, and the scientist gives his attention to the amount of work done and not to the time it takes to do it.

Furthermore, the scientist is not interested in the amount of effort it takes to do work. If you attempt to lift a chair on which you are sitting you are not doing work at all, in a scientific sense, because you are accomplishing nothing; and if you wear yourself out lifting at the corner of a house, it is not work, but a foolish waste of strength. It is the result secured, not the time and effort expended, that really counts, and this is all the scientist takes into account in considering how much work has been done.

How shall we measure work? We measure milk by the quart, sugar by the pound, dress goods by the yard, land by the acre, wood by the cord. We measure illuminating gas by the thousand cubic feet. Coal is bought by the ton. We pay for cement sidewalks or paving by the square foot or square yard. We sometimes pay for city lots at ten, a hundred, or a thousand dollars "per front foot." How shall we measure work?

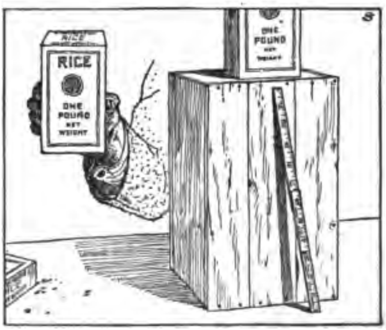


FIG. 205. A foot pound is the amount of work required to lift 1 pound to the height of 1 foot.

If we use the English system, the unit of work is the foot pound. This is the work done by a force of 1 pound acting through a space of 1 foot; that is, it is the amount of work required to lift 1 pound to a height of 1 foot. How much work is

required to lift a brick that weighs 5 pounds to the top of a box that is 3 feet high?

Power. Sometimes we are interested in knowing how fast a given piece of work can be done by a machine. In this case, the element of time is considered. By power is meant the rate or speed of doing work. In order to understand what this means, let us study the following problem:

To carry 100 bricks, each weighing 5 pounds, to a mason on a scaffold which is 11 feet high would require 500×11 or 5500 foot pounds of work, whether the task were performed in an hour or a minute. When we measure the work in this way, the time consumed plays no part; only the force and the distance are considered. But it is frequently very important to know how long it will take to do the work or how fast a machine can work. Suppose, then, that a machine is used to haul the 100 bricks up to the scaffold and that it can do this in 10 seconds. The machine will then be doing work at the rate of 550 foot pounds a second. We could then describe this machine by saying that it is able to do 550 foot pounds of work every second. An engineer or a mechanic would describe such a machine by saying it is a machine of one horse power.

James Watt, an Englishman who made great improvements on the steam engine, described his engines in this way, for he thought that a good horse was able to do work at the rate of 550 foot pounds per second and keep it up all day. The fact is that an average horse can do work only about three quarters as fast as this.

A horse power is the work which must be done in order to lift 550 pounds 1 foot in 1 second.

To compute the horse power of an engine, find the number of foot pounds it can do in one second and divide this number by 550:

$$\text{Horse power (H.P.)} = \frac{\text{foot pounds per second}}{550}$$

What is meant by a 10-horse-power engine? How many horses would it take to do the work of such an engine?

How many pounds will a 100-horse-power engine lift 1 foot in 1 minute?

How far will it lift 100 pounds in a minute?

Work done by machines and by the forces of nature. Let us remind ourselves that it is not alone men and boys, women and girls, horses, oxen, mules, and other living things that are capable of doing work, but that work on the grandest scale is done by the forces of nature and by hundreds of different kinds of machines which employ a large number of different kinds of force. Thus we speak of the work done by running water, the steam engine, the dynamo, heat, the sun's rays, the ocean's waves, and many other things. Did you ever see the sidewalk pushed up and broken by the roots of a tree growing underneath? Work was being done in this case also.

Energy. Another word, and the idea for which it stands, must now be studied. We stand before Niagara Falls and think of the tremendous amount of energy in the great mass of falling water; or we look upon the

throbbing locomotive and estimate the energy by which a train of cars may be drawn so rapidly from city to city. A baseball pitcher rolls up his sleeve and shows the well-developed muscles, and we do not wonder that his arm possesses energy enough to throw the ball with such speed. We ride upon an electric car and wonder where the energy is concealed by which the car is moved along the tracks so swiftly and smoothly. Think of the energy wrapped up in a ton of gunpowder; of the energy set loose in a stroke of lightning, in the outburst of a volcano, or in the heat and light of the sun, as it stirs into activity the giant forces of the winds and the waves of the sea. Study the world of energy about you and you may conclude that it is even more interesting and more important to mankind than is the world of matter.

What is energy? The question we naturally ask first about energy is, What is it? This is a difficult question to answer, but we have found out what energy can do, and we say that energy is the capacity to do work. In other words, anything that can do work has energy. A short review will show us that we have been studying energy for some time.

Different forms of energy. A moving hammer drives the nail into the wood; a moving steamship hits the wharf with great force; the moving plow tears apart the earth and throws the furrow over; the moving water turns the wheel of the mill; and the moving air sets the windmill to spinning about. Anything that has motion has the power to do work; it has mechanical energy, or the energy of motion. Turn back to Chapter

Twenty-two and note that you have already studied this form of energy.

Heat can lift water (Exercise 2, page 243); it can force the mercury up the tube of the thermometer (Exercise 3, page 253); it can melt ice and drive the molecules of water apart so that the liquid water is converted into steam. Heat causes mighty winds to sweep across the surface of the earth and vast ocean currents to carry millions of tons of water across the beds of the sea. It is evident that heat can do work; heat also is a form of energy, and one that you have studied.

Turn back and review page 283. The light drives the little machine about, breaks down the molecules of silver in the photographic plate, and builds food in the leaves of plants. Light also is a form of energy. Without knowing it, we studied energy when we studied light.

Electricity falls in a tremendous lightning stroke from the cloud, shattering the tree that it strikes; or it flows silently along a wire, ringing our doorbells for us, carrying our messages by telephone or telegraph, pulling our trolley cars and trains, and driving machinery of a hundred different kinds. Electricity also must have energy, since it can do work in so many different ways.

A charge of dynamite explodes and a great mass of rock and earth is hurled high in the air. Gasoline explodes in the cylinder of an automobile engine and the heavy machine is driven along the street. A basket-ball player eats her food and from it gets the strength which she uses in playing the game.

FIG. 206. Chemical energy released. An explosion of a submarine mine containing 100 pounds of guncotton.

The kind of energy which is in the dynamite, gasoline, and food is called chemical energy. It is stored in the molecules, and when the molecules are broken up the energy is released and the work is done. In the earlier chapters of this book we studied many examples of chemical changes that released energy in the form of heat or light.

Motion, heat, light, electrical energy, and chemical energy can all do work. They are all different forms of energy.

Transformation of energy. One of the great facts about energy is that one form of energy can be transformed,* or changed, into other forms. The motion of the hammer is changed into the heat of the nail (Exercise 7, page 247); the light of the sun is changed into heat (Exercise 16, page 251); electrical energy can be changed to heat, light, or motion, and the chemical energy of our

food is turned into the heat and strength of our bodies. Perhaps the story of some of the transformations of energy with which you are familiar may help to make this subject clear to your mind.

When coal is burned under the boiler of a steam engine, the chemical energy of the coal is changed to heat, and the heat sets the molecules of the water into more rapid motion and, pushing them far apart, produces steam. The steam molecules hammer on the piston of the engine and push it on, thus producing motion, or mechanical energy, in that machine. This mechanical energy may, in turn, be used to run a dynamo and thus produce the energy of the electric current. The electrical energy can be carried along wires to any distance, and at any place we desire it may again be changed into the energy of heat or light, or it may be used to produce motion in all kinds of machines. So it is that constantly, all around us, one form of energy is being changed into another for the convenience of man.

But we have not yet seen the most interesting example of this principle of the transformation of energy. We must ask other questions: Where did the coal get its energy to give to the fire, the steam, the motion of the engine and dynamo, the electricity and the light? What produced the coal?

Coal, as you know, is produced from plants. Where do plants get their energy? Think a moment. Can a plant develop and grow in the dark? You know it cannot, and the great secret is out. The story sounds like the story of "the house that Jack built." Here

it is: the energy of the sunlight is transformed in the plant into chemical energy, and this is stored up in the coal. Then the energy of the coal is turned into heat by the burning of the coal and that into other forms of energy, until it appears in the light which comes from the electric bulb. We light our houses by sunshine which fell upon the earth millions of years ago.

The conservation of energy. The greatest fact that we have learned about energy is that it cannot be either created or destroyed; that, like matter, it can only be changed from one form to another. This is the law of the conservation of energy: When one form of energy is lost, an equal amount of energy in another form always appears to take its place. Thus when motion is checked, heat is produced. When electrical energy disappears, heat, light, or motion appears. When heat is absorbed, an increased movement in the molecules follows; and the light which shines out into the darkness is not lost but warms the objects on which it falls. We live in a changing world, but not in a fleeting, vanishing world. Both matter and energy exist on and on; when they seem to drop out of existence, they have only changed to other forms.

Some questions about energy. Would it be possible to build a "perpetual motion machine," — a machine that would run on and on and give power to other machinery, without being provided with energy from some outside source?

What kind of energy does your body use? What kind of energy does a waterwheel use? What kind of

energy does a steam engine use? Does an electric light turn all the energy of the electricity that comes to it into light? Why is a Mazda lamp more economical than the old-fashioned carbon-filament electric lamp? What animal gives off "cold light," — light that is produced without wasting any energy in heat?

Where do we go for energy to carry on the world's work? What kind of energy is used to lift the water to the mountain tops? What is the source of the energy that causes the winds to blow? Where did the energy come from that is stored in food?

Active and stored energy. Energy may be active, like the energy of the water that pours over Niagara Falls, the light that beats down from the sun, or the electrical energy that causes a motor to revolve. It may be stored up and inactive, as the energy in a reservoir of water collected on a mountain height, a spring that has been tightly wound, or the chemical energy that is in a piece of dynamite, a lump of coal, or a slice of bread.[1]

Energy is stored in the rock that is lying high on the mountain side. It becomes active when the rock is loosened from its resting place and crashes down to the valley below. By making a dam across a mountain stream above Johnstown, Pennsylvania, vast amounts of energy were stored in a great reservoir of water, to be drawn on as it was needed to run the machinery of that busy manufacturing city. By the bursting of the dam this energy was in a moment released, and the

[1] Energy in its active form is called kinetic energy. In its stored or inactive form it is called potential energy.

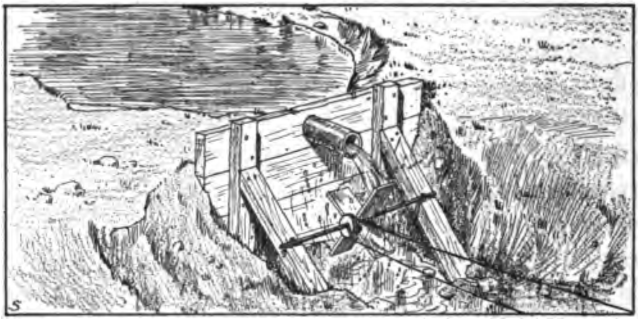


FIG. 207. When the water falls on the wheel, the energy stored in it becomes active.

active mechanical energy of the flood of water which rushed madly down the valley carried death and destruction to everything in its path.

Other illustrations of stored energy may be found in the hammer held high in the air ready to strike; the loaded gun; the engine standing still but with the steam hissing hot and ready to do its work; a load of coal; a tank of gasoline; the charged electric battery; a baseball pitcher "winding up," or a tennis player ready to send a swift serve over the net.

Some facts we have learned. Energy is the ability to do work.

Energy is the cause, work is the effect.

Motion, heat, light, electrical energy, and chemical energy are different forms of energy.

One form of energy can be changed into other forms, but energy, like matter, is indestructible.

Energy may be active, or it may be stored in an inactive form.

CHAPTER THIRTY-FOUR

AIDS TO OUR WORK

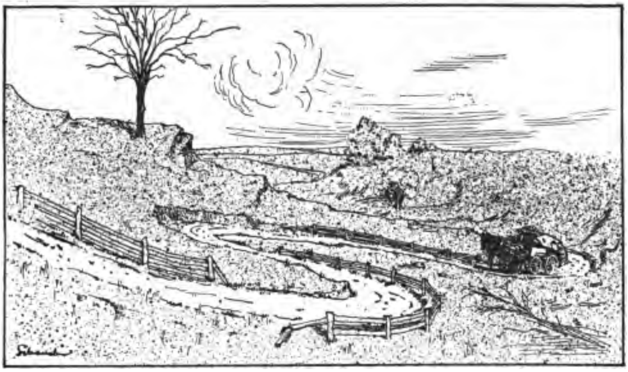


FIG. 208. The road is a machine which enables the horses to lift the load gradually to the top of the hill.

No animal except man ever makes use of a machine. For example, a mole or a prairie dog will burrow in the ground in order to provide itself with a place of shelter and safety; a bird will build its nest for a home out of sticks or grass. But in neither case does the animal make use of any tools except those with which nature has provided it; the mole uses its feet and claws and the bird its bill and, occasionally, its feet.

A man might dig a well by simply removing the earth with his hands, but this is not the way a man goes about such a task. In order to do the work more easily, he brings to his aid a pickax to loosen the soil and a shovel to lift it out. When the depth of the well becomes greater than the length of the handle of his shovel, he may use a bucket with a rope attached to it to draw out

the earth. He may also place a pulley above him and, passing the rope over it, make it possible to elevate the bucket of earth by pulling on the rope from the bottom of the well. In some cases a man may even call to his aid very complex well-digging machinery to make a hole in the earth, and then use another machine which he calls a pump to draw the water from the well.

What a machine is. A machine is anything that lightens the labor of man or gives him more efficiency in his work.[1] It may be some device like a needle, hammer, saw, screw driver, or crowbar that enables man to use his own strength to better advantage; it may be something like a wagon, plow, or binder that makes it possible for him to use the strength of animals in his labor; or a machine like the windmill, waterwheel, automobile, or steam engine, that turns the vast forces of nature to the accomplishment of his work.

The present time an age of machinery. The present time, more than any other period in the history of the world, is an age of machinery.

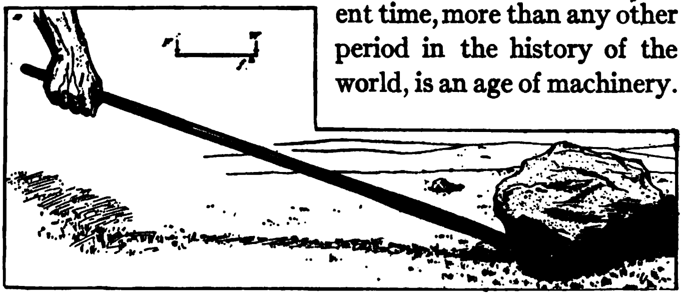


FIG. 209. A simple machine which increases the lifting power of man.

[1] A tool is but the extension of a man's hand, and a machine is but a complex tool. And he that invents a machine augments the power of a man and the well-being of mankind. — HENRY WARD BEECHER.

By the aid of machines man travels over sea and land and flies through the air. By the aid of a machine man is able to haul immense trainloads on railways or even over ordinary roads with no rails to run upon. By other machines he sends his thoughts across the ocean and talks with those who are hundreds or even thousands of miles away. Very many times a day we use some instrument or tool to help us at even our simplest tasks. If you will carry out the following exercises you will realize how greatly man's activities differ from those of the mole, the bird, and other lower animals.

Fig. 210. A machine which gives an advantage in lifting power and in the direction in which the force is applied.

Exercise 1. Begin in the morning and make a list of all the tools, implements, and mechanical devices that you use throughout the day, — comb, spoon, knife, toothpick, door hinges, poker, street car, needle, sewing machine, baseball bat, and other things. What is the total number?

Exercise 2. Make a list of the machines that you see in use in one day and record the work that is done by each. Think what our lives would be like if all this work had to be done by hand.

Two advantages in the use of machines. A team of horses cannot draw a heavily loaded wagon straight up the face of a very steep hill. But if a road to the top of the hill be laid out so that it winds back and forth across

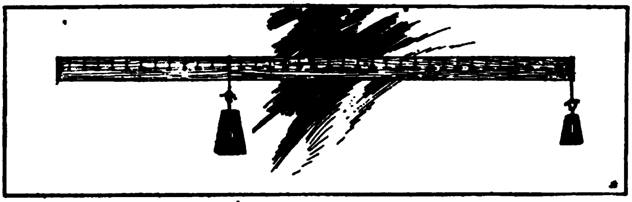


FIG. 211.

the hillside and rises with only a gentle grade, the horses can take the load to the summit of the hill.

The amount of work required to lift the wagon to the hilltop is the same whether it goes up the steep hillside or is brought up the more gradually rising road. For example, if the wagon and its load weigh 3000 pounds and the hill is 100 feet high, it will take 300,000 foot pounds of work to bring the wagon to the top (page 339). The advantage in the road is that it allows the horses to lift the load a shorter distance for each foot that they travel, — to wind back and forth across the hillside, lifting the load little by little until they get it to the top. A greater force could pull the wagon along a short, steep road straight up the hill; the lesser force which the horses are able to exert can do the same work if it is allowed to act through a long distance and raise the load gradually. It is thus evident that by increasing the distance through which a force acts, its power to move a heavy body can be increased.

Exercise 3. Set a sharp-edged block on the corner of a table and balance a yardstick across it; or suspend the yardstick as shown in Figure 211. Hang a 3-pound weight 6 inches from the center on one arm and a 1-pound weight

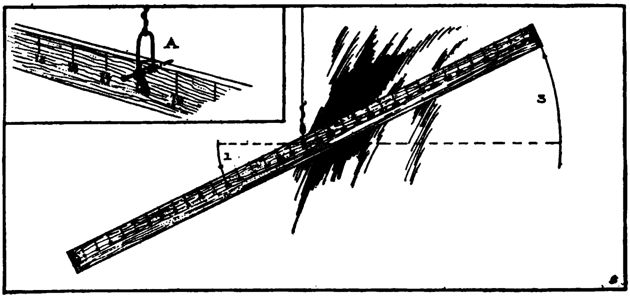


FIG. 212.

on the end of the other arm. The two weights will exactly balance each other. With a slight touch of the finger to assist it, the 1-pound force lifts a weight of 3 pounds. It is clearly seen that by the simple machine which we have arranged, the lifting power of the 1-pound force has been increased threefold.

Now, remove the weights and raise or lower the long arm of the stick so that the 1-pound weight moves 1 foot; at the same time measure the distance that the 3-pound weight moves. It will be found that the 3-pound weight moves 4 inches, exactly $\frac{1}{3}$ as far as the 1-pound weight moves. We have found that a 1-pound force acting through a space of 1 foot will lift a 3-pound weight through a distance of 4 inches.

The purpose of giving the small force the long arm of the stick is to allow it to act through a longer distance when the weight is moved; for a small force acting through a long distance can lift a heavy weight through a short distance. We see, therefore, that one advantage in using machines is that by

FIG. 213. A machine that gives an advantage in the speed with which the object is moved.

means of them we can make forces act through longer distances than the objects are moved, and thus magnify the power of the forces to do heavy work. When a man pries a stone out of the ground with a crowbar (Fig. 209), he greatly increases his lifting power by moving the end of the crowbar in his hands through a comparatively long distance while the stone is raised a much shorter distance. When we raise a bucket of water with a windlass (Fig. 210), we gain in lifting power by making the hand move through a wide circle while the rope is wound up and the bucket raised only a short distance. The lower pair of scissors shown in Figure 216 is used for cutting tin and iron. Do you see how the force acts through a greater distance than the blades move and that there is a gain in power when scissors of this kind are used? A "mechanical advantage" is secured by using machines of this kind.

Figure 213 is a whirligig, merry-go-round, or flying-jinny. By pushing on the arm close to the center the

boy on the ground is able in a revolution to move the ends of the arms much farther than he himself travels. In other words, with the whirligig there is a gain in the distance that the boys riding on the arms are moved.

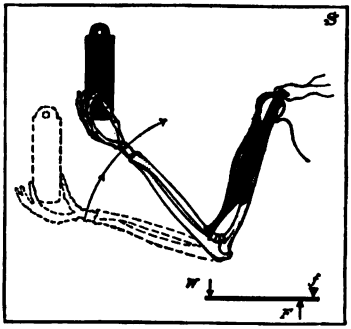


FIG. 214. An arrangement that gives an advantage in speed.

We must not forget, however, that the merry-go-round is heavier to turn when one pushes on the arm near the center than when the pushing is done at the end of the arm; that when we gain in the distance we move an object, we do so at the expense of the force. But with light objects we are willing to use more force in order to move them rapidly, and we have many machines that are designed to increase the speed and distance through which objects can be moved.

How far does the key of a typewriter move when it is pushed down? How far does the type move when it strikes the ribbon? How far does the key of a piano move, and how far does the hammer travel when it is thrown against the string?

Notice that the type and the hammer move through the longer distance in the same time that the key is moving through the shorter distance. By this device the velocity of the type and hammer is greatly increased, and because of this their striking force, or momentum

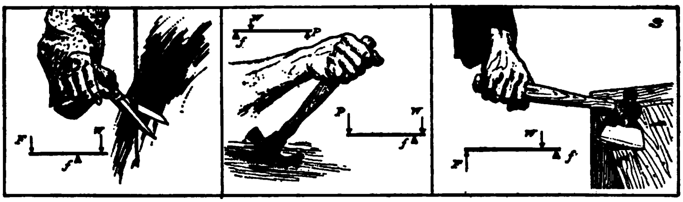


FIG. 215. Three examples of levers.

(page 221), also is greatly increased. Thus the type makes a sharper and more distinct mark, and in the case of the hammer even a slight touch of the finger on the key produces a clear and distinct sound.

The upper pair of scissors in Figure 216 is a pair of office shears for cutting paper. Do you see how distance is gained in the motion of the blades?

How far do the feet move in making a revolution on the pedals of a bicycle? How far does the bicycle move along the road with one revolution of the pedals? Is it easier to walk or to ride a bicycle up a hill? Is the bicycle a machine for gaining force or for gaining distance?

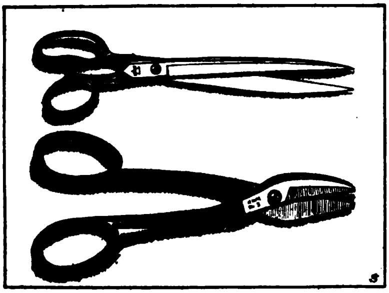
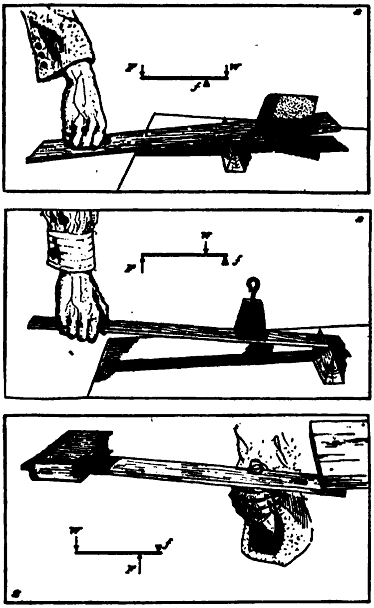


FIG. 216.

The preceding illustrations have shown that there is a second advantage in the use of machines: <u>we can increase the distance an object is moved, and thus move a light object through a longer distance.</u>



FIGS. 217, 218, and 219. The three classes of levers.

All machines combinations of a few simple machines. Since we so constantly use tools and machinery, it is very desirable that we understand something of their action. For our comfort it may be said at once that almost all machines, no matter how complex, are only combinations of a few very simple machines. These simple machines are the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw.

The lever. The crowbar is a good example of a lever, the most commonly used of all machines. Notice that in Figure 209 one end of the crowbar is pushed well under the stone, that a smaller stone has been crowded under the bar quite near the stone to be lifted, and that the man's hand is at the other end of the crowbar.

The point where the bar rests on the smaller stone is called the fulcrum.

The force applied by the hand or in any other way will be called simply the force.

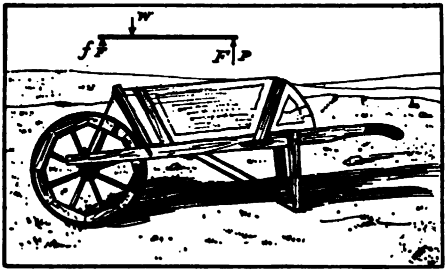


Fig. 220. What two advantages are gained by the use of this machine? (See Fig. 135.)

The part of the lever between the fulcrum and the hand of the man is called the force arm.

The weight to be lifted or the object to be moved is called the weight, or the resistance.

The part of the lever between the fulcrum and the stone that is being lifted is the weight arm, or the resistance arm.

Some experiments with the lever. Arrange a lever for yourself, either indoors or outdoors. One of considerable length, with a rather heavy weight, will be best. Perform the following experiments:

Exercise 3. Place the fulcrum near the weight. The force arm is long and the weight arm is short. Is the weight lifted easily? Which moves farther, your hands or the weight you are lifting? What is the advantage of using a lever of this kind?

You will notice that the weight moves through a comparatively small distance and the force applied moves through a much greater distance in the same time. In other words, with such a lever we use a small force through

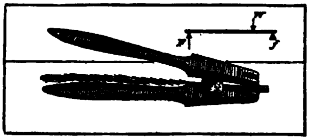


FIG. 221.

a long distance and move a heavy weight slowly through a short distance. It is a machine by the use of which we gain in force at the expense of distance.

Exercise 4. Place the fulcrum in the center so that the force and weight arms are of the same length. You must now apply to the force arm a force equal to the weight of the object in order to lift it. Which moves farther, the force or the weight?

Would you gain either force or distance by the use of such a lever?

Exercise 5. Place the fulcrum near the hands so that the force arm is short and the weight arm long.

Is the weight lifted easily or with difficulty? Does it require more force to lift it this way or to lift it with your hands? Does your hand or the object you are lifting move farther?

With a lever of this kind we may use great force slowly and cause a small body to move rapidly. In other words, with such a lever we lose in force but gain in the distance the object is moved. A pair of pliers or the sugar tongs will illustrate this.

These experiments have shown very clearly what may be called the law of the lever; namely, the longer the force arm in comparison with the weight arm, the heavier the weight that can be lifted, but the shorter the distance through which the weight will be moved. When we wish to move a heavy object only a short distance, we make the

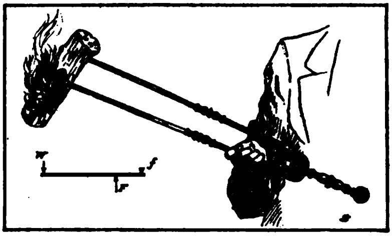


FIG. 222.

force arm long and the weight arm short. When we wish to move a light object rapidly and through a long distance, we put it on the end of a long weight arm and take the short force arm in the hand.

Classes of levers. There are three classes of levers. When the fulcrum is between the force applied and the weight, we have a lever of the first class. The levers we have used in our experiments are all of this class.

When the weight lies between the fulcrum and the force applied, we have a lever of the second class (Fig. 218).

In levers of the third class the force is applied between the fulcrum and the weight (Fig. 219). Levers of this class all gain in distance, but the force must be greater than the weight. Study Figure 219 and see if you understand why this must be true.

Exercise 6. Decide whether the following tools are levers of the first, second, or third class: nutcracker, a pair of scissors, a wheelbarrow, the oar of a boat, a hammer as it is used in pulling a nail, a hatchet as it is used in pulling a nail, a pair of tongs, the forearm of a man (Fig. 215), a pitchfork as it is used in pitching hay.

The wheel and axle. The windlass, the capstan, and the steering wheel of a ship are good examples of the wheel and axle. They are all special forms of the lever, and work according to the same principles. This

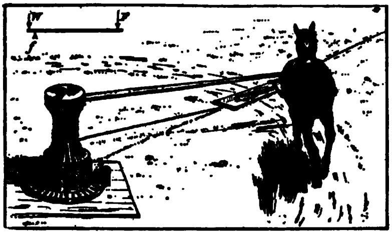


FIG. 223.

you will readily understand if you will consider the crank which turns the windlass (*F* to *f*) the force arm, and one half the diameter of the windlass (*f* to *W*) the shorter weight arm (Fig. 210). It is evident that as the windlass is turned about, the hand at *F* travels much faster than the rope is wound up, — that it is a machine by which we lose in the distance through which the object is moved, but a machine which gives us the power to raise a heavier weight than could be lifted without it.

What force would be necessary to lift a weight of 300 pounds with a windlass whose axle is 1 foot in diameter and whose handle is 3 feet long?

Like the windlass, the capstan is a lever, and because the capstan often has a very long force arm, great power can be secured from it. The great length of the force arm explains how, by the use of the capstan, a single horse can draw a house along the street — the horse travels many feet at the end of his long lever while the house may be moved only a few inches.

The pulley. There are two kinds of pulleys, the fixed and the movable. The fixed pulley gives us no advantage in power or in speed; it only changes the direction in which the force is applied (Fig. 225). This kind of pulley makes it possible by pulling downward

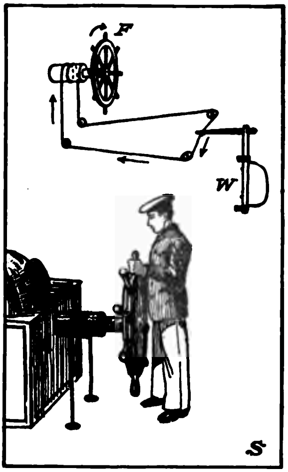


FIG. 224. Explain how the course of the boat is determined by the movements of the wheel.

to raise a bucket of water from the well, and for the horse, by pulling, to lift the hay to the top of the barn. Do we need to explain the advantage of the fixed pulley in cases like these? Look about you and find other cases where the fixed pulley is used.

The movable pulley is a device that enables us to gain in force. Examine Figure 226 and you will see that the hand supports only half of the weight which is attached to the block of the pulley. Perhaps you can see also that if you should draw the end of the rope a foot upward the pulley and its weight would rise only half a foot; the lifting force moves through twice the distance that the weight is raised. A pulley of this kind, therefore, makes it possible to lift twice as heavy a weight as can be raised without it.

Figure 227 shows the arrangement of what is known as a block and tackle. The pulley blocks, *A* and *B*, make it possible to use as many pulleys as are desired, side by side. The pulleys in *A* are fixed and those in *B* are movable. The weight to be lifted is attached to the block *B*. The force is applied to the loose end of the rope, which is first attached to the block *A* and then

passed successively over each pulley in both blocks. The figure shows a system of 2 movable and 3 fixed pulleys. Notice that there are 6 ropes supporting the weight, and that to shorten each of these ropes and raise the boat 1 foot the men must draw the rope downward 6 feet. By this system every pound of force applied will lift 6 pounds of weight, but what we gain in power is lost in distance. The force must move 6 feet to raise the weight 1 foot.

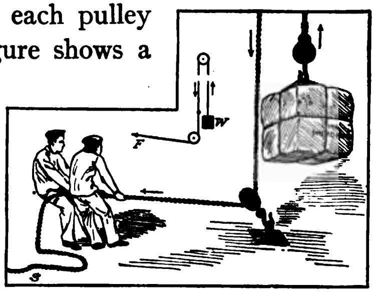


FIG. 225. The fixed pulley changes the direction in which the force is applied.

The inclined plane. If a barrel of flour is to be lifted into a wagon, a long board can be used, with one end resting on the wagon and the other upon the ground. The barrel of flour may be rolled up the inclined plane thus formed. The man or boy who does the work will find that he can do it much more easily in this way than by lifting the barrel directly into the wagon.

Any inclined surface used in this way is an inclined plane. A road running up the side of a hill or around a mountain is an example of an inclined plane. It is easier to climb a mountain by a road that winds about and rises gradually than to go straight up a very steep slope.

The law of the inclined plane. This law is the same as the law for other machines; the longer the distance

through which the weight is moved, compared with the height it is lifted, the less power it takes to do the work.

FIG. 226. A movable pulley doubles the lifting power of the force.

For example, let us suppose that a man wishes to load a barrel of flour which weighs 200 pounds into a wagon that is 3 feet high. If we do not count the friction of the barrel, by using a board 9 feet long he can roll the barrel into the wagon with a force of $66\frac{2}{3}$ pounds. That is, he moves the barrel through 3 feet of space to lift it 1 foot, and it will take only $\frac{1}{3}$ as much force to do this as it would take to lift the barrel straight up.

The wedge. The wedge is a machine that is used to get great sidewise force. It tapers gradually to a point, and as it is driven or pushed forward, the thicker part of the wedge exerts its sidewise pressure. Examine Figure 230 and you will see that because its length is greater than its thickness, the wedge travels forward farther than it pushes the two sides of the log apart, so that we are here gaining in force and losing in distance. In reality, the wedge is simply a movable inclined plane, or two such planes joined together at their bases. The force applied to it is generally a blow from a mallet or hammer, which cannot readily be measured, so that it

is difficult to estimate the mechanical advantage gained. The friction to be overcome is very great.

Wedges are made of iron or other hard material, and are used for splitting logs or for lifting heavy weights through small distances. Leaning chimneys and masonry walls have been pushed into an upright position by driving wedges in on the lower side. Nails, needles, pins, knives, axes, and many other cutting tools are made on the principle of the wedge. We use the sidewise force from these tools to push or break apart the materials we are working on, and we make the tools thin at the edge or point and gradually thickening so that we shall have the mechanical advantage of their pushing forward a considerable distance while they exert a side force through only a small distance.

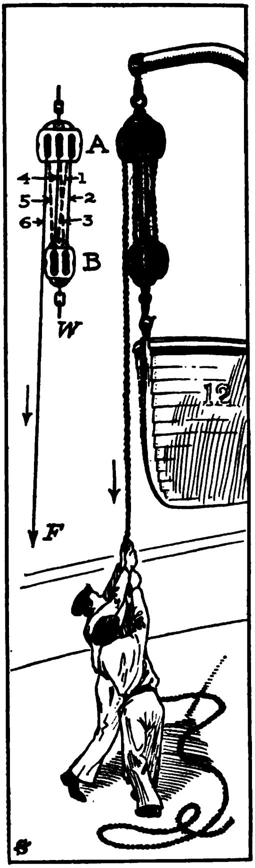


FIG. 227. The lifting power of the force is multiplied by 6.

The screw. The screw is a combination of the lever and the inclined plane. In the jackscrew (Fig. 231), the handle by which the screw is turned is the lever, and the threads of the screw are the inclined plane which the weight

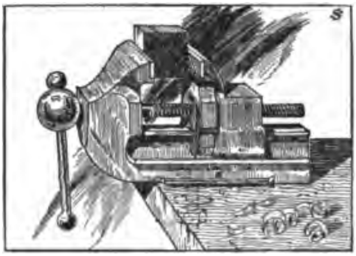
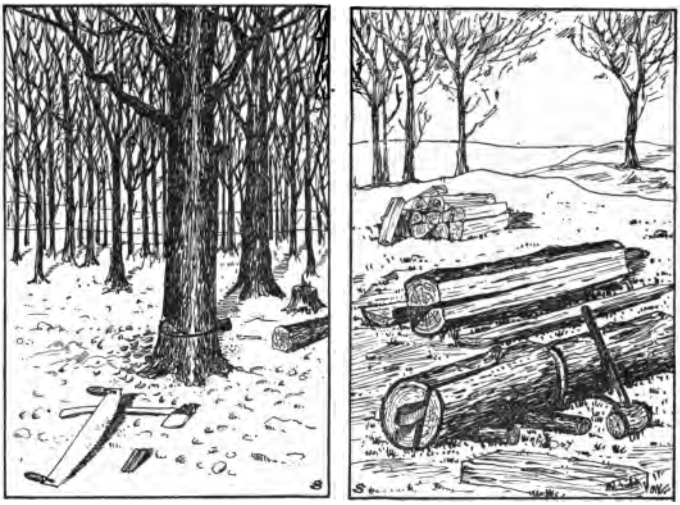


FIG. 228.

slides up. When the force acting on the end of the lever has made one revolution, the weight which rests upon the top of the screw has evidently been lifted through a vertical distance equal to the distance between the threads. Has the hand which furnishes the power moved much farther than the weight has been lifted? For what purposes are jackscrews used?

The most common example of a screw is the bolt and nut. Why is a wrench used in turning a nut on a bolt? The screw press and the vise (Fig. 228) are other examples of the screw. Do not be satisfied by merely studying about these machines, but carefully examine a bolt and nut; go to the carpenter's or blacksmith's shop and see a vise.

An excursion to the railroad station. Stand beside one of our modern railroad engines and find in it many of the simple machines you have just studied. Of course you knew before this that a machine is not simply a device for making use of the power in a man's hand, but also a means of utilizing the power of steam, of heat or electricity, of running water, or of any other form of energy. What is the force applied in the case of the locomotive? Where is the point of application of the force? What is the weight or resistance to be overcome? Note the length of the levers, the diameters of the wheels and axles, and other features of this powerful machine.



FIGS. 229 and 230. The work of a simple but very powerful machine.

An important truth. One important fact about machines should be clearly understood. No machine can create or increase energy. We can get out of a machine only the amount of work we put into it. In fact, in all machines, some energy is lost by the friction of the parts of the machine upon each other. The lever is an example of a machine in which there is but little friction, and its efficiency may be rated as nearly 100 per cent; on the other hand, in some machines the efficiency may not be more than 60 per cent. By the word efficiency is understood the quotient of the energy regained, called the useful work, divided by the total energy expended. Thus:

$$\text{Efficiency} = \frac{\text{useful work accomplished}}{\text{total energy expended}}$$

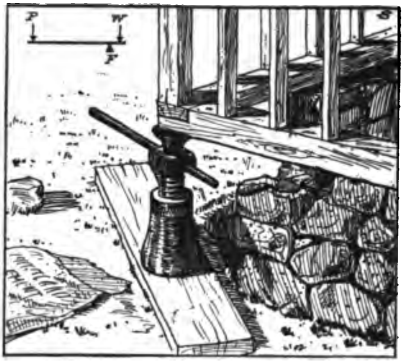


FIG. 231. A combination of the lever and the inclined plane.

A question to think about. If a machine cannot create or increase energy, and if we must do as much work as we get from it — or even more — the question arises, What are the advantages in using machines, and why use them at all? Several good answers to this question can be given:

(1) Machines enable us to change the direction of a force that we are applying to our work, as when a load of hay is lifted from the wagon to the upper part of the barn.

(2) They enable us to use other forces than our own, as when we use the horse to lift the hay or when the energy of coal or falling water is made to do our work.

(3) By means of a machine we are able to apply power where it would be impossible to do so without the machine. We can draw water from a deep well by a pump; we can sew on a button with a needle; with an auger we can bore a hole in a piece of wood.

(4) Many machines, like the dynamo and the steam engine, make it possible to use and transform one form of energy into another form.

(5) A machine enables us to move heavy bodies by the use of a small force.

(6) It is possible through the use of machines and great force to move bodies very rapidly, to get great speed of motion.

Mention other great advantages derived from the use of machines.

APPENDIX

Table of the More Common Chemical Elements, with Their Symbols and Atomic Weights

Aluminium	Al	27.1	Lead	Pb	207.20
Antimony	Sb	120.2	Lithium	Li	6.94
Argon	A	39.88	Magnesium	Mg	24.32
Arsenic	As	74.96	Manganese	Mn	54.93
Barium	Ba	137.37	Mercury	Hg	200.6
Bismuth	Bi	208.0	Neon	Ne	20.2
Boron	B	11.0	Nickel	Ni	58.68
Bromin	Br	79.92	Nitrogen	N	14.01
Cadmium	Cd	112.40	Osmium	Os	190.9
Calcium	Ca	40.07	Oxygen	O	16.00
Carbon	C	12.00	Phosphorus	P	31.04
Chlorin	Cl	35.46	Platinum	Pt	195.2
Chromium	Cr	52.0	Potassium	K	39.10
Cobalt	Co	58.97	Radium	Ra	226.0
Copper	Cu	63.57	Selenium	Se	79.2
Fluorin	F	19.0	Silicon	Si	28.3
Glucinum	Gl	9.1	Silver	Ag	107.88
Gold	Au	197.2	Sodium	Na	23.00
Helium	He	4.00	Strontium	Sr	87.63
Hydrogen	H	1.008	Sulfur	S	32.06
Iodin	I	126.92	Tin	Sn	118.7
Iridium	Ir	193.1	Tungsten	W	184.0
Iron	Fe	55.84	Uranium	U	238.2
Krypton	Kr	82.92	Zinc	Zn	65.37

INDEX

A star (*) after a page number indicates that an illustration of the subject appears in connection with the reference.

Book Notices